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(54) GLASS-COATED WATER HEATER CONSTRUCTED OF MULTIPLE METALS

(57) A water heater (100) including a tank (110) for holding heated water made at least partially of mild steel, a heat exchanger for heating water made at least partially of stainless steel, an inlet (130) to add water to the tank (110), an outlet (135) to withdraw water from the tank (110), and an anode connected to the tank (110). An inner water-facing surface of the tank (110) is coated at least partially with a protective coating, and a water-facing surface of the heat exchanger is coated at least partially with a protective coating.

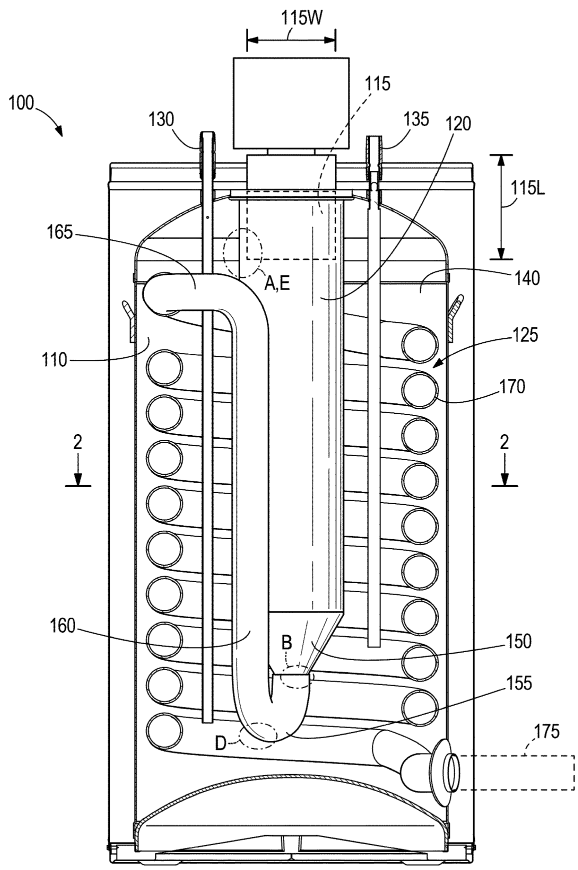

FIG. 1

EP 3 441 695 A1

Description

BACKGROUND

[0001] Commercial gas water heaters are primarily of two designs on the market: glass-lined mild steel tanks with anode protection and unlined stainless steel tanks without anode protection. Such water heaters generally include a tank for holding water to be heated and a heat exchanger in heat exchange relationship with water in the tank to transfer heat from a source of heat (e.g., a burner, heat pump condenser coil, or heating element) to the water in the tank. Each of the designs has advantages and disadvantages and has modes of failure relating to the construction of the tank and the operation of the heat exchanger.

SUMMARY

[0002] According to the present invention there is provided an apparatus and method as set forth in the appended claims. Other features of the invention will be apparent from the dependent claims, and the description which follows.

[0003] One aspect of the invention provides a water heater comprising a tank constructed at least partially of a mild steel and adapted to hold water to be heated; a heat exchanger constructed at least partially of a stainless steel, adapted to heat the water in the tank; an inlet to add the water to the tank; an outlet to withdraw the water from the tank; and an anode assembly electrically connected to the tank, wherein an inner water-facing surface of the tank is at least partially coated with a first protective coating; wherein a water-facing surface of the heat exchanger is at least partially coated with a second protective coating.

[0004] In one aspect of the invention, the first protective coating and the second protective coating comprise glass. In one aspect of the invention, the first protective coating comprises epoxy. In one aspect of the invention, the heat exchanger is constructed at least partially of a ferritic or a duplex stainless steel. In one aspect of the invention, the surface of the heat exchanger is at least partially coated with a white metal blast with 25-50 grit or 50-80 grit arranged between the glass coating and the ferritic or the duplex stainless steel. In one aspect of the invention, the heat exchanger is constructed at least partially of an austenitic stainless steel. In one aspect of the invention, the surface of the heat exchanger is at least partially coated with a white metal blast with 25-50 grit or 50-80 grit arranged between the glass coating and the austenitic stainless steel. In one aspect of the invention, the anode assembly is a sacrificial anode assembly or a powered anode assembly. One aspect of the invention further comprises a powered anode supplying current density of at least about 40 mA/m^2. One aspect of the invention further comprises a constant current anode supplying current density of greater than or equal to about 100 mA/m^2. In one aspect of the invention, the stainless steel comprises 304L stainless steel. In one aspect of the invention, the stainless steel comprises at least one high heat flux region on the heat exchanger. One aspect of the invention further comprises a transition sensitive zone of the heat exchanger and a burner, wherein the stainless steel comprises one or more of the following regions on the heat exchanger: (i) an area that is within line of sight contact with the burner, (ii) a transition location within the transition sensitive zone, (iii) a baffle within the transition sensitive zone, (iv) an elbow or a bend within the transition sensitive zone, and (v) a location within about 3 burner lengths from the burner. In one aspect of the invention, the stainless steel comprises at least one high heat flux region on the heat exchanger having a surface temperature during burner operation greater than or equal to about 30 °F higher than the water temperature. In one aspect of the invention, the stainless steel comprises at least one high heat flux region on the heat exchanger, wherein the mild steel and the at least one high heat flux region comprised of the stainless steel are separated by a region of reduced heat flux by a distance of about 3 inches to about 6 inches. In one aspect of the invention, the stainless steel comprises at least one high heat flux region on the heat exchanger, wherein the mild steel comprises at least one region on the tank less than about 3 inches from the at least one high heat flux region comprised of the stainless steel, wherein the at least one region comprised of mild steel is thicker than a region of the tank comprised of mild steel greater than about 3 inches from the at least one high heat flux region comprised of stainless steel. In one aspect of the invention, the coated stainless steel comprises at least one high heat flux region on the heat exchanger, wherein the anode assembly provides increased corrosion resistance of the at least one high heat flux region comprised of the coated stainless steel or wherein of the anode assembly provides increased corrosion resistance of at least one region comprised of mild steel less than about 3 inches from the at least one high heat flux region comprised of coated stainless steel. One aspect of the invention, further comprising high heat flux regions constructed of mild steel and non-high heat flux regions constructed of stainless steel. In one aspect of the invention, high heat flux regions do not comprise mild steel. In one aspect of the invention, condensing areas, when present, do not comprise a mild/stainless steel interface.

[0005] Other aspects of the invention will become apparent by consideration of the detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006]

Fig. 1 is a vertical cross-section view of a water heater according to a first construction of the present invention.

Fig. 2 is a cross-section view of the water heater of Fig. 1 taken along line 2-2.

Fig. 3 is a vertical cross-section view of a water heater according to a second construction of the present invention.

Fig. 4 is a cross-section view of the water heater of Fig. 3 taken along line 4-4.

DETAILED DESCRIPTION

[0007] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways.

[0008] The modifier "about" used in connection with a quantity is inclusive of the stated value and has the meaning dictated by the context (for example, it includes at least the degree of error associated with the measurement of the particular quantity). The modifier "about" should also be considered as disclosing the range defined by the absolute values of the two endpoints. For example, the expression "from about 2 to about 4" also discloses the range "from 2 to 4". The term "about" may refer to plus or minus 10% of the indicated number. For example, "about 10%" may indicate a range of 9% to 11%, and "about 1%" may mean from 0.9-1.1. Other meanings of "about" may be apparent from the context, such as rounding off, so, for example "about 1" may also mean from 0.5 to 1.4.

[0009] Figs. 1 and 2 illustrate a first type of water heater 100 according to the present invention. The water heater 100 includes a tank 110, a gas burner 115, a combustion chamber 120, and a flue 125. The tank 110 includes a water inlet 130 for the supply of cold water from a source of water and a water outlet 135 for the delivery of hot water from the tank 110 to a hot water consuming device (e.g., a shower, sink, dishwasher, laundry machine). An inner surface of the tank 110 an outer surface of the combustion chamber 120, and an outer surface of the flue 125 may be termed "water-facing surfaces" because they face an interior space 140 in the tank 110 in which water is heated and stored between draws. Water in the interior space 140 is in contact with the water-facing surfaces (or more technically, with a coating on the water-facing surfaces, as will be discussed below).

[0010] The gas burner 115 has a length 115L and width 115W. The gas burner 115 burns a combustible mixture of fuel (e.g., gas) and air to generate products of combustion in the combustion chamber 120. The burner 115 may extend partially into the combustion chamber 120 through the top of the combustion chamber 120. The burner 115 fires downwardly into the combustion chamber 120 and may therefore be termed a down-firing burner. The products of combustion flow from the combustion chamber 120 into the flue 125. The walls of the combustion chamber 120 and flue 125 are heated by the products of combustion, and the heat is transferred to the water in the interior space 140.

[0011] The flue 125 includes a narrowing portion 150, a first elbow 155, a vertical section 160, a second elbow 165, and a coil 170. The narrowing portion 150 communicates between the lower end of the combustion chamber 120 and the first elbow 155. The narrowing portion 150 receives the products of combustion from the combustion chamber 120. The narrowing portion 150 is shaped as a nozzle and causes the velocity of the products of combustion to increase as they are delivered to the first elbow 155.

[0012] The first elbow 155 communicates between the narrowing portion 150 and the vertical section 160. The first elbow 155 receives the products of combustion from the lower end of the narrowing portion 150. The bend of the first elbow 155 changes the flow direction of the products of combustion from downward (as received from the narrowing portion 150) to upward (as delivered to the vertical section 160). The products of combustion are therefore delivered to the vertical section 160 in a rising direction.

[0013] The vertical section 160 communicates between the first elbow 155 (at the bottom end of the vertical section 160) and the second elbow 165 (at the top end of the vertical section 160). The products of combustion rise in the vertical section 160 and are delivered to the second elbow 165. The second elbow 165 communicates between the top end of the vertical section 160 and the top of the coil 170. The bend of the second elbow 165 turns the flow direction of the products of combustion from upward (as received from the top of the vertical section 160) to substantially horizontal (as delivered to the coil 170). The products of combustion are therefore delivered to the top end of the coil 170 in a substantially horizontal flow direction.

[0014] The coil 170 communicates between the second elbow 165 and an exhaust assembly 175 of the water heater 100. The coil 170 receives the products of combustion from the second elbow 165 in a generally horizontal flow direction and guides the products of combustion in a downward spiraling path. The coil 170 winds around a major portion of the combustion chamber 120 (except the very top of the combustion chamber 120 in the illustrated construction), the narrowing portion 150, the first elbow 155, and the vertical section 160. The bottom end of the coil 170 communicates with the exhaust assembly 175 through a hole in the lower portion of the tank 110 to vent the products of combustion from the system.

[0015] Figs. 3 and 4 illustrate a second type of water heater 200 according to the present invention. The water heater 200 includes a tank 210, a power gas burner 215 (i.e., including a blower 217), a combustion chamber 220, a plurality of flues 225, and a bottom plenum 227. The tank 210 includes a cold water inlet 230 for the supply of cold water from a source of water to the bottom of the tank 210 and a preheated water inlet 233 for the delivery of preheated water to an upper portion of the tank 210 (a preheater heat exchanger may be positioned, for example in the space under the tank 210 or may be provided as a separate unit). The water heater 200 also includes a hot water outlet for drawing hot water from the tank 210 to be delivered to a hot water consuming device (e.g., a shower, sink, dishwasher, laundry machine). An inner surface of the tank 210 and the outer surface of the combustion chamber 220 and flues 225 may be termed "water-facing surfaces" because they face an interior space 240 in the tank 210 in which water is heated and stored between draws.

[0016] The gas burner 215 has a length 215L and width 215W. The gas burner 215 burns a combustible mixture of fuel (e.g., gas) and air to generate products of combustion in the combustion chamber 220. The burner 215 may extend partially into the combustion chamber 220 through the top of the combustion chamber 220. The burner 215 fires downwardly into the combustion chamber 220 and may therefore be termed a down-firing burner. The combustion chamber 220 includes a flat bottom end 245 with a plurality of holes 247 in it to communicate with the plurality of flues 225. The combustion chamber 220 is relatively wide and acts as a plenum, reducing the pressure of the products of combustion and distributing the products of combustion to the multiple flues 225. The products of combustion flow from the combustion chamber 220 into the flues 225. The walls of the combustion chamber 220 and flues 225 are heated by the products of combustion, and the heat is transferred to the water in the interior space 240.

[0017] Each flue 225 is a generally cylindrical tube. In some embodiments, the flues 225 can be outfitted with internal baffles or can be flattened into ribbons with a wavy profile to enhance heat transfer. The top end of each flue tube 225 communicates with the interior of the combustion chamber 220 through the above-mentioned holes 247 in the flat bottom end 245. The bottom end of each flue tube 225 communicates with the bottom plenum 227. The bottom plenum 227 collects the products of combustion from the multiple flue tubes 225 and exhausts the products of combustion through an exhaust assembly similar to the exhaust assembly 175 in Fig. 1.

[0018] Each of the two types or configurations of water heaters 100, 200 illustrated in Figs. 1-4 includes high heat flux regions. The term "high heat flux region" is used to indicate a portion of the water heater 100, 200 having special characteristics disclosed herein that can lead to accelerated corrosion.

[0019] Referring to Figs. 1-4, examples of high heat flux regions are regions that meet one or more of the following criteria: locations with line-of-sight contact to the burner, due to high flame temperatures or radiation heat transfer from the burner ("line-of-sight regions" indicated with "A" in Figs. 1 and 3); transition locations from a larger chamber or tube to a smaller chamber or tube, due to a reduction in boundary layer thickness and some minor increases in turbulence resulting from an increase in velocity of the gas ("transition regions" indicated with "B" in Figs. 1 and 3); on baffled heat exchangers or heat exchangers with enhanced surface features, in regions which increase gas turbulation ("turbulation regions" indicated with "C" in Fig. 3); elbows or bends resulting in high heat flux due to increased gas turbulation and reduction of the boundary layer thickness adjacent portions of the elbow ("elbow regions" indicated with "D" in Fig. 1); and locations within approximately three burner lengths or widths from the burner, resulting in high heat flux due to high gas temperature ("proximal regions" indicated with "E" in Figs. 1 and 3).

[0020] Regions B (transition), C (turbulation), and D (elbow) are only a concern in portions of the heat exchanger in which the combustion gases are sufficiently hot to pose a concern for loss of glass coating. Typically, this will be within the first half of the heat exchanger in condensing units or within the first two-thirds of the heat exchanger in non-condensing units.

[0021] "Line-of-sight" means there is an unobstructed path between the source of heat and the region, such that the region is exposed to radiant heat from the heat source. Examples of line-of-sight regions A are the sidewall of the combustion chamber 120 alongside the lower end of the burner 115 in Fig. 1 and the central portion of the flat bottom 245 of the combustion chamber 220 which is directly under the bottom end of the burner 215 in Fig. 3. Examples of transition regions B are the transition from the narrowing portion 150 to the first elbow 155 in Fig. 1 and the transition from the combustion chamber 220 to each of the flues 225 in Fig. 3.

[0022] "Turbulation region" means a baffle or other enhanced surface feature which causes the products of combustion to dwell or move in a manner that enhances heat transfer. An example of a potential turbulation region C is inside the multiple flues 225 of the water heater 200 illustrated in Figs. 3-4, when baffles 250 are installed or the flue tubes 225 are formed into flat, wavy ribbons. An examples of an elbow region D is the first elbow 155 in Fig. 1.

[0023] For the purposes of finding a proximal region, the term "burner length" may mean the major dimension of the burner and "burner width" may mean the minor dimension of the burner. In the illustrated constructions, the burner lengths and widths are noted above (115L, 115W, 215L, 215W). Proximal regions experience high heat flux because the temperature of the products of combustion is highest close to the burner. Examples of proximal regions E are the portions of the combustion chambers 120, 220 near the portion of the burner 115, 215. The high heat flux regions A-E are not mutually exclusive; a region may qualify as a high heat flux region under multiple categories. For example, a line-of-sight region A is often also going to be a proximal region E.

[0024] In certain embodiments, relatively low-heat regions toward the end of the heat exchanger are also important, especially in condensing gas water heaters. Such regions may be referred to as "condensing areas" because it is primarily where the gas condenses into a liquid. Additionally or alternately, other non-high heat flux regions may be important.

[0025] Material composition is an important design consideration for any type of water heater. The choice of the materials, however, is necessarily affected by their cost. As such, commercial gas water heaters currently on the market are primarily of two designs: glass-lined mild steel tanks with anode protection and unlined stainless steel tanks without anode protection. Each design has advantages and disadvantages, and each has modes of failure relating to the construction of the tank and the operation of the heat exchanger.

[0026] Both mild steel and stainless steel commercial gas water heaters typically have extremely high duty cycles compared to residential water heaters. An average duty cycle for a commercial unit may be about 15% (i.e., burner active 15% of a given period such as a 24-hour day), or it may be as high as 40% or more. By comparison, a typical duty cycle for a residential water heater may be about 6%, although higher water usage conditions can occur. The demands of a high duty cycle may lead to a higher rate of corrosion or a shorter lifetime for a commercial water heater, or for a residential water heater with high usage.

[0027] In glass-coated mild steel tanks with anode protection, water-facing surfaces are lined or coated with glass to reduce susceptibility to corrosion. The terms "glass-lined" and "glass-coated" are interchangeable. For consistency, the term "glass-coated" will be used to refer to all surfaces that are lined or coated with glass. Glass coating is usually applied only to water-facing surfaces to reduce cost. Under high duty cycles, sections of glass coating on the water-facing surfaces of the heat exchanger will become degraded. Where the glass coating is degraded, the underlying mild steel of the water-facing surface is exposed to water in the tank and eventually corrodes and fails.

[0028] In some high efficiency gas water heaters, glass is also applied to gas-facing condensing areas. However, glass coating on the gas-facing side is difficult and expensive. For example, hydrogen is soluble in mild steel during glassing, and if hydrogen is released from the steel during cooling after the glass has solidified, it can cause defects in the glass, such as fish scaling.

[0029] Stainless steel is generally more corrosion resistant than mild steel, but is typically more expensive and more difficult to process during manufacturing. Thus to lower overall cost, among other reasons, commercial stainless steel tanks have not been glass coated before. Likewise, a combination of mild and stainless steel can complicate the production process and lead to significant galvanic corrosion at mild/stainless steel interfaces. However, corrosion of exposed water-facing stainless steel surfaces can be severe in areas with high chloride or high sulfate water conditions. Mineral deposits on the water-facing stainless steel surfaces can also lead to high levels of corrosion near or under the deposits ("under deposit" corrosion).

[0030] For example, uncoated stainless steel gas water heaters may be prone to failure at weld locations and at certain locations on the heat exchanger. Likewise, glass-coated mild steel gas water heaters typically fail at locations on the heat exchanger. Without being limited to theory, this may be due to high surface temperatures on the heat exchanger accelerating degradation of glass coatings and/or increasing rates of deposition on exposed water-facing steel surfaces.

[0031] Such deposits may include limescale, calcium carbonate, calcium bicarbonate, calcium sulfate, calcium oxalate, barium sulfate, manganese sulfide, magnesium bicarbonate, magnesium hydroxide, magnesium oxide, silicates, aluminum oxide hydroxides, aluminosilicates, copper, phosphates, wustite, hematite, magnetite, or nickel ferrite, for example. Deposits on water-facing surfaces of uncoated stainless steel water heaters or on exposed mild steel surfaces of degraded glass-coated water heaters may lead to high levels of under deposit corrosion around or under the deposits.

[0032] Stainless steel surfaces could be further protected by anodes, but even modest protection for a fully exposed stainless steel surface area (e.g., the heat exchanger surface area) may require current densities that can lead to high levels of hydrogen generation. A high level of hydrogen is generally considered undesirable because it can lead to water quality issues, such as hydrogen sulfide smell. Moreover, in an uncoated tank, it can be difficult to detect areas with increased current density requirements and for anode protection to adapt to corrosion conditions caused by high surface temperatures and surface conditions (i.e. deposits).

[0033] Disclosed herein are hybrid commercial gas water heaters with markedly improved corrosion resistance, especially in high chloride or high sulfate water conditions, at minimal additional cost. In the hybrid design, portions of the water heater (100, 200) include mild steel and portions of the water heater (100, 200) include stainless steel. In certain embodiments, stainless steel is included only at high heat flux regions (A, B, C, D, E), to reduce cost, and mild steel is included in other regions. Alternately, stainless steel may be included in additional regions, such as a condensing area that does not require glass coating on the gas side of the condensing region. In certain embodiments, all water-facing surfaces may be glass coated.

[0034] Additionally or alternately, certain embodiments may include anode protection. The stainless steel used in the present invention may be, for example, 304L stainless steel. In certain embodiments, 304L stainless steel may comprise up to about 0.03 wt% C, up to about 2.00 wt% Mn, up to about 0.045 wt% P, up to about 0.030 wt% S, up to about 0.75 wt% Si, greater than or equal to about 18.0 wt% and less than or equal to about 20.0 wt% Cr, greater than or equal to about 8.0 wt% and less than or equal to about 12.0 wt% Ni, and up to about 0.10 wt% N, the balance being Fe and incidental elements and impurities.

[0035] In the hybrid design, glass coating may protect mild steel and stainless steel water-facing surfaces from corrosion, such as under deposit corrosion. Although glass coatings will eventually degrade and expose underlying steel surfaces, especially at high heat flux regions, anode protection may provide additional corrosion resistance. Anode protection may be especially effective against under deposit corrosion of exposed stainless steel in high chloride or high sulfate water conditions.

[0036] Surprisingly, glass coating (even when degraded in high usage applications) was found sufficiently intact as to greatly reduce hydrogen generation on stainless steel surfaces with anode protection. Even in a condition of severe degradation, the glass coating on the heat exchanger provided about 80% coverage to the heat exchanger surfaces. Earlier testing showed that stainless steel in aggressive water conditions could be protected at a current density equal to about 80 mA/m^2, and further testing suggested that a current density of up to 500 mA/m^2 was required to protect a mild steel heat exchanger during burner (115, 215) operation. In contrast, a glass coated stainless steel heat exchanger was found to provide significantly better corrosion protection than either a commercial glass coated mild steel heat exchanger or an uncoated stainless steel heat exchanger, as can be seen in the data of Table 1.

[0037] Furthermore, because glass coatings typically degrade fastest in high heat flux regions as disclosed herein, it is possible to effectively position anodes in the hybrid design for maximum protection. This is unlike organic coatings, which do not degrade in predictable regions.

[0038] Since experience has shown the inventors that up to about 20% of the heat exchanger will be exposed in conditions of severe degradation, the maximum required current may be determined to be about 100 ma/m^2 to essentially eliminate mild/stainless steel interface corrosion issues. In certain embodiments, the maximum current must be greater than about 100 ma/m^2 times about 20% of the HX surface in meters. In certain other embodiments, such as residential water heaters, the maximum current may be lower (because less steel is exposed from degradation of the glass coating): about 100 ma/m^2 times about 10% of the HX surface in meters or about 100 ma/m^2 times about 5% of the HX surface in meters, for example.

[0039] Corrosion tests were conducted in small corrosion cells filled with 1000 ppm NaCl water at 150 °F at different current densities. Surprisingly, it was found that the current density (46 ma/ft^2) available in a degraded glass coated hybrid tank provided good protection to exposed stainless steel in high chloride water. The current density (3.3 ma/ft^2) available in an uncoated stainless steel tank provided insufficient protection in high chloride water despite having a total current 2.4 times higher than the heavily degraded hybrid tank. An uncoated stainless steel tank had less corrosion pitting than an uncoated tank without anode protection, but, surprisingly, for the corrosion pits that formed, the pit depth was just as deep. Meanwhile, the hybrid tank had a significantly lower total current requirement, and the heat exchanger was completely protected from corrosion pitting.

Table 1

Test Conditions	Current Density (mA/m^2)	Current (mA) for 199,000 Btu/hr condensing coil product	Avg. No. Pits per Panel	Avg. Depth of Pits (mils)
No Anode Protection	0	0	8	11.4
Uncoated Tank	3.3	450	1	15.2
Hybrid Tank with severely degraded glass lining	46	185	0	N/A

[0040] In some embodiments, the anode is a powered anode (e.g., anode with detection), which has a known resistance. The powered anode will generate a known current as a function of the anode's resistance and the voltage applied. For example, the anode may periodically shut off and measure the tank potential referenced to its known open circuit potential; then it may automatically adjust current up or down based on this measurement. Current density, as used in Table 1 and throughout this specification, is the amount of current per unit exposed, water facing area.

[0041] A minimum current density of about 40 mA/m^2 is needed to reduce the likelihood that glass coating will debond from stainless steel. As more water-facing surface area is exposed due to glass coating degrading in high heat flux regions, the minimum current density of about 10 mA/m^2 can be maintained by increasing current (i.e., increasing voltage across the anode). The inventors have also learned through testing that at a current density of 90-100 mA/m^2 the effects of galvanic corrosion between stainless steel and mild steel are essentially neutralized (i.e., the rates of corrosion of the mild steel and stainless steel are about what they would be in the absence of the effects of galvanic corrosion).

[0042] In certain embodiments, glass coating of stainless steel in the disclosed hybrid design has a minimum adhesion level of 1 on ASTM B196, 2001 bond tests. This may essentially eliminate under film corrosion. Epoxy coatings on stainless steel, in contrast, were found to exhibit significant under film corrosion and increased surface corrosion. Further testing showed that anode protection enhanced resistance of undercut corrosion of glass coated stainless steel, but that it harmed the performance of organic coated stainless steel due to cathodic disbondment of epoxy coating. Alternately, an epoxy coating may be used on mild steel surfaces. Although cathodic disbondment may occur on either mild or stainless steels, for stainless steels the delaminated film may create a crevice, which can cause significant pitting corrosion. This cause of pitting corrosion is not an issue for mild steel.

[0043] Surface cracking tests in high chloride water conditions showed that an adhesion level of at least 1 on the ASTM B196, 2001 bond test can be obtained with a white metal blast with 25-50 grit or 50-80 grit, for Ferritic (439) and Duplex (2101) stainless steel. For Austenitic stainless steels (304, 316), adequate adhesion can be obtained by the same blasts, or a detergent clean and water rinse with no blast.

[0044] In certain embodiments, the presence of exposed stainless steel may increase corrosion of mild steel surfaces. In certain embodiments, the thickness of mild steel surfaces located near high heat flux glass coated stainless steel surfaces may be increased by three times or more from the minimum thickness required for pressure vessel components. Thicker mild steel surfaces may prevent water heater failure or extend water heater lifetime.

[0045] For example, a typical water heater has a relatively thick head to meet pressure vessel standards, but a relatively thin-walled flue (or fire tube) to encourage efficient heat transfer. If both the head and flue are made of mild steel, the mode of failure will typically be corrosion of the flue. It is understood that galvanic corrosion can arise where different metals are in close proximity, and this is true when using stainless steel for the flue and mild steel for the head. However, the inventors have surprisingly discovered that the thickness of the head material can offset the more rapid rate of corrosion.

[0046] In one test, for example, corrosion on the mild steel top head of the unit (about 0.25 inches thick) was increased by about 30% when operated with a stainless steel flue. Nevertheless, the overall lifetime of the hybrid unit was still about 2.5 times greater, because for a comparable all mild steel water heater, the mild steel components on the heat exchanger are much thinner (about 0.06 inches). The markedly improved lifespan of the hybrid design was observed even though the tested unit was under-protected by anode protection (average current density of about 42 ma/m^2).

[0047] In certain embodiments, distance between stainless steel surfaces and mild steel surfaces may be increased. Alternately or additionally, the heat flux may be reduced in the region between two metals by design modifications. Testing in high conductivity water (about 900 μS/cm) has shown minimal impact based on the distance between mild steel and a large area of exposed stainless steel. Surprisingly, in low conductivity water (e.g., about 45 μS/cm) the required protective current density on the mild steel, which had about a 1-inch separation from the large area of stainless steel, was more than about 100% higher than the current density required to protect the mild steel surface with a separation of about 6 inches or about 10 inches. Anode protection of mild steel surfaces about 1 inch away from an exposed stainless steel surface may require a current density about 33% more than mild steel surfaces about 3 inches away from an exposed stainless steel surface. In certain embodiments, mild steel surfaces may be separated from high heat flux regions by about 3 to about 6 inches, or more.

[0048] In certain embodiments, the firing section of the burner is extended such that a stainless/mild steel interface at a joint is not in a high heat flux region and/or no high heat flux region is within about 3 inches of a mild steel region of the tank (e.g., the head). In certain embodiments, a transition region includes a heavier wall. In certain embodiments, a transition region includes a transition piece: for example, a stainless steel transition cone and small diameter tube and a mild steel large diameter tube where the gradual transition of the cone allows the glass coating to survive. In certain embodiments, an elbow and the region about 5 pipe diameters away from the bend are stainless steel, allowing the glass coating to stay intact.

[0049] In certain embodiments, anodes may be positioned near joints or other high heat flux regions. In certain embodiments, a hybrid water heater may include improved detection of exposed steel surfaces. Orientation of an anode close to a steel joint may result in greater protection (more negative voltage) at a lower current density. For example, Table 2 shows how in a degraded tank, the mild steel interface can be protected by improved anode geometry.

Table 2: Large Stainless Steel Defect with Small Mild Steel Defects

Power Anode Electrode Location	Current (ma)	Steel Potential @ 1 in. (V)	Steel Potential @ 10 in. (V)
Anode Centered on Steel Defects	55.7	-1.03	-2.01

(continued)

Power Anode Electrode Location	Current (ma)	Steel Potential @ 1 in. (V)	Steel Potential @ 10 in. (V)
Anode Centered on Joint	51.4	-1.32	-1.16
Anode Centered on Stainless	63.3	-1.05	-1.05

[0050] However, it is difficult to predict an effective anode geometry in a new tank where the glass coating has not yet degraded. The inventors have discovered that if mild steel samples (such as a ¼ inch defect) are placed at the mild steel interface and 6 inches from the interface, the correct anode configuration can be determined by measuring when the potential at the interface is about 0.15 V more negative than potentials at 6 inches to either side of the interface (Table 3). This determination is less easily made in high conductivity water conditions (e.g., 50 μS/cm or higher).

Table 3: Measurement of Potentials - 0.25 square inch defects

15 μS/cm water (70F)	Potential 6 in.	Centered on mild/stainless steel interface	Potential over stainless steel
Anode Protection Centered on Small Mild Steel Defects	-0.823 V	-0.520 V	-0.423 V
Anode Protection Centered over Interface	-0.865 V	-1.11 V	-0.767 V
Anode Protection Centered over Large Stainless Steel Defect	-0.651 V	-0.65 V	-0.93 V
50 μS/cm water (70F)	Potential 6 in.	Centered on mild/stainless steel interface	Potential over stainless steel
Anode Protection Centered on Small Mild Steel Defects	-0.853 V	-0.801 V	-0.983 V
Anode Protection Centered over Interface	-0.998 V	-1.094 V	-0.751 V
Anode Protection Centered over Large Stainless Steel Defect	-0.833 V	-0.83 V	-0.57 V
850 μS/cm water (70F)	Potential 6 in.	Centered on mild/stainless steel interface	Potential over stainless steel
Anode Protection Centered on Small Mild Steel Defects	-1.125 V	-1.135 V	-1.322 V
Anode Protection Centered over Interface	-1.132 V	-1.211 V	-1.012 V
Anode Protection Centered over Large Stainless Steel Defect	-1.281 V	-1.14 V	-1.049 V

[0051] The disclosed hybrid water heater may be designed to allow the set-point for anode protection near a mild steel/stainless steel interface to be increased without a significant increase in the total current. Tests indicated that increasing the anode set-point voltage for the short electrode nearest the stainless/mild steel interface and therefore increasing anode current by about three times on a short anode closest to a large defect at the top of a combustion tube resulted in improved potential on the defect area (from -0.45V to -0.65V). Overall current was only increased by 23% due to the interaction in protection provided by the two electrodes, which resulted in a lower anode current for the longer anode (Table 4). This technique may allow for enhanced protection of the mild steel/stainless steel interface without significantly increasing anode currents.

Table 4

		Voltage (V)	Current (mA)	Total Current(mA)	Potential (V)
Trial 1	Short Anode	2.65	40	166 ma	-0.45
	Long Anode	2.65	126		

(continued)

		Voltage (V)	Current (mA)	Total Current(mA)	Potential (V)
Trial 2	Short Anode	3.1	112	205 ma	-0.63
	Long Anode	2.65	83		

[0052] Since high heat flux regions are easily identified in the hybrid design disclosed herein, anode protection can be easily adjusted for different kinds of anodes, such as sacrificial (e.g., magnesium), anode with detection (see U.S. Patent No. 7,372,005, incorporated by reference herein in its entirety), or constant current, for example. In certain embodiments, additional sacrificial anodes are positioned near the mild/steel interface. In another embodiment, the set-point potential (control potential) on electrodes closest to a joint may be increased. In yet another embodiment, the constant current of electrodes closest to a joint may be increased.

[0053] On the gas-facing side of the disclosed hybrid design, significant galvanic corrosion can occur at mild/steel interfaces in condensing areas. There are several ways to modify the hybrid design in order to prevent this. In some embodiments, the mild/steel interface is moved upstream to a non-condensing area of the heat exchanger. In other embodiments, both the mild and stainless steel interface are glass-coated (on the gas-facing side). Unlike the water side of the tank, glass coating may only be needed within about 2 inches of the mild/steel interface. In yet other embodiments, the mild steel part of the mild/steel interface is thicker than the stainless steel part of the interface.

[0054] Thus, the invention provides, among other things, a water heater including a tank for holding heated water made at least partially of mild steel, a heat exchanger for heating water made at least partially of stainless steel, an inlet to add water to the tank, an outlet to withdraw water from the tank, and an anode connected to the tank, where an inner surface of the tank is coated at least partially with a protective coating, and the heat exchanger is coated at least partially with a protective coating. Various features and advantages of the invention are set forth in the following claims.

[0055] Attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

[0056] All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

[0057] Each feature disclosed in this specification (including any accompanying claims, abstract and drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

[0058] The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

Claims

1. A water heater comprising:

    a tank constructed at least partially of a mild steel and adapted to hold water to be heated;
    a heat exchanger constructed at least partially of a stainless steel, adapted to heat the water in the tank;
    an inlet to add the water to the tank;
    an outlet to withdraw the water from the tank; and
    an anode assembly electrically connected to the tank,
    wherein an inner water-facing surface of the tank is at least partially coated with a first protective coating;
    wherein a water-facing surface of the heat exchanger is at least partially coated with a second protective coating.

2. The water heater of claim 1, wherein the first protective coating and the second protective coating comprise glass.

3. The water heater of claim 1, wherein the first protective coating comprises epoxy.

4. The water heater of any preceding claim, wherein the heat exchanger is constructed at least partially of a ferritic or a duplex stainless steel.

5. The water heater of claim 4, wherein the surface of the heat exchanger is at least partially coated with a white metal blast with 25-50 grit or 50-80 grit arranged between the glass coating and the ferritic or the duplex stainless steel.

6. The water heat of any one of claims 1 to 3, wherein the heat exchanger is constructed at least partially of an austenitic stainless steel.

7. The water heater of claim 6, wherein the surface of the heat exchanger is at least partially coated with a white metal blast with 25-50 grit or 50-80 grit arranged between the glass coating and the austenitic stainless steel.

8. The water heater of any preceding claim, wherein the anode assembly is a sacrificial anode assembly or a powered anode assembly.

9. The water heater of any preceding claim, further comprising a powered anode supplying current density of at least about 40 mA/m^2.

10. The water heater of any preceding claim, further comprising a constant current anode supplying current density of greater than or equal to about 100 mA/m^2.

11. The water heater of any preceding claim, wherein the stainless steel comprises 304L stainless steel.

12. The water heater of any preceding claim, wherein the stainless steel comprises at least one high heat flux region on the heat exchanger.

13. The water heater of any preceding claim further comprising a transition sensitive zone of the heat exchanger and a burner, wherein the stainless steel comprises one or more of the following regions on the heat exchanger: (i) an area that is within line of sight contact with the burner, (ii) a transition location within the transition sensitive zone, (iii) a baffle within the transition sensitive zone, (iv) an elbow or a bend within the transition sensitive zone, and (v) a location within about 3 burner lengths from the burner.

14. The water heater of any preceding claim, wherein the stainless steel comprises at least one high heat flux region on the heat exchanger having a surface temperature during burner operation greater than or equal to about 30 °F (16.7°C) higher than the water temperature.

15. The water heater of any preceding claim, wherein the stainless steel comprises at least one high heat flux region on the heat exchanger, wherein the mild steel and the at least one high heat flux region comprised of the stainless steel are separated by a region of reduced heat flux by a distance of about 3 inches (7.6cm) to about 6 inches (15.2cm).

16. The water heater of any one of claims 1 to 14, wherein the stainless steel comprises at least one high heat flux region on the heat exchanger, wherein the mild steel comprises at least one region on the tank less than about 3 inches (7.6cm) from the at least one high heat flux region comprised of the stainless steel, wherein the at least one region comprised of mild steel is thicker than a region of the tank comprised of mild steel greater than about 3 inches (7.6cm) from the at least one high heat flux region comprised of stainless steel.

17. The water heater of any one of claims 1 to 14, wherein the coated stainless steel comprises at least one high heat flux region on the heat exchanger, wherein the anode assembly provides increased corrosion resistance of the at least one high heat flux region comprised of the coated stainless steel or wherein of the anode assembly provides increased corrosion resistance of at least one region comprised of mild steel less than about 3 inches (7.6cm) from the at least one high heat flux region comprised of coated stainless steel.

18. The water heater of any preceding claim, further comprising high heat flux regions constructed of mild steel and non-high heat flux regions constructed of stainless steel.

19. The water heater of any preceding claim, wherein high heat flux regions do not comprise mild steel.

20. The water heater of any preceding claim, wherein condensing areas, when present, do not comprise a mild/stainless steel interface.

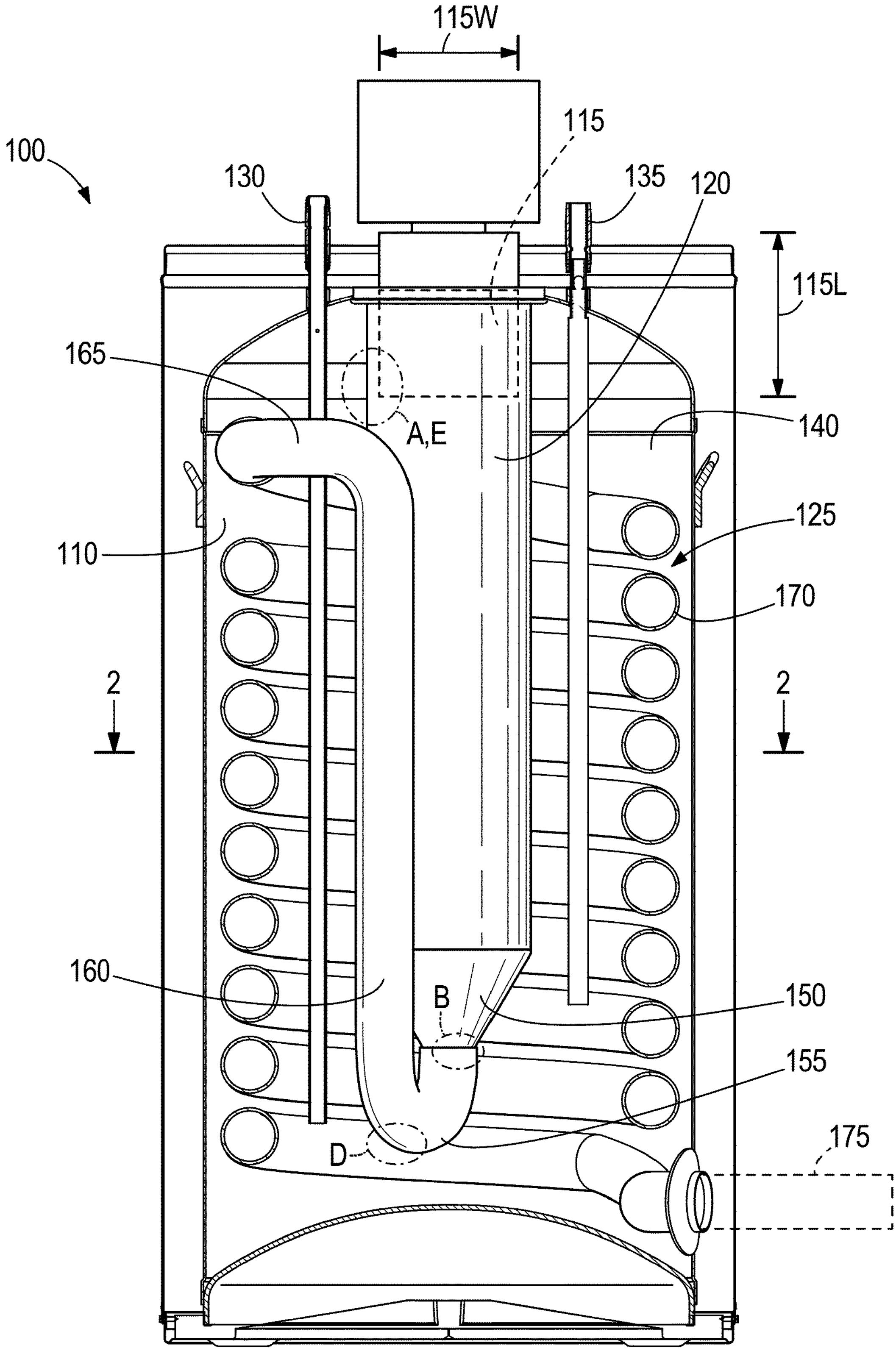
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FIG. 1

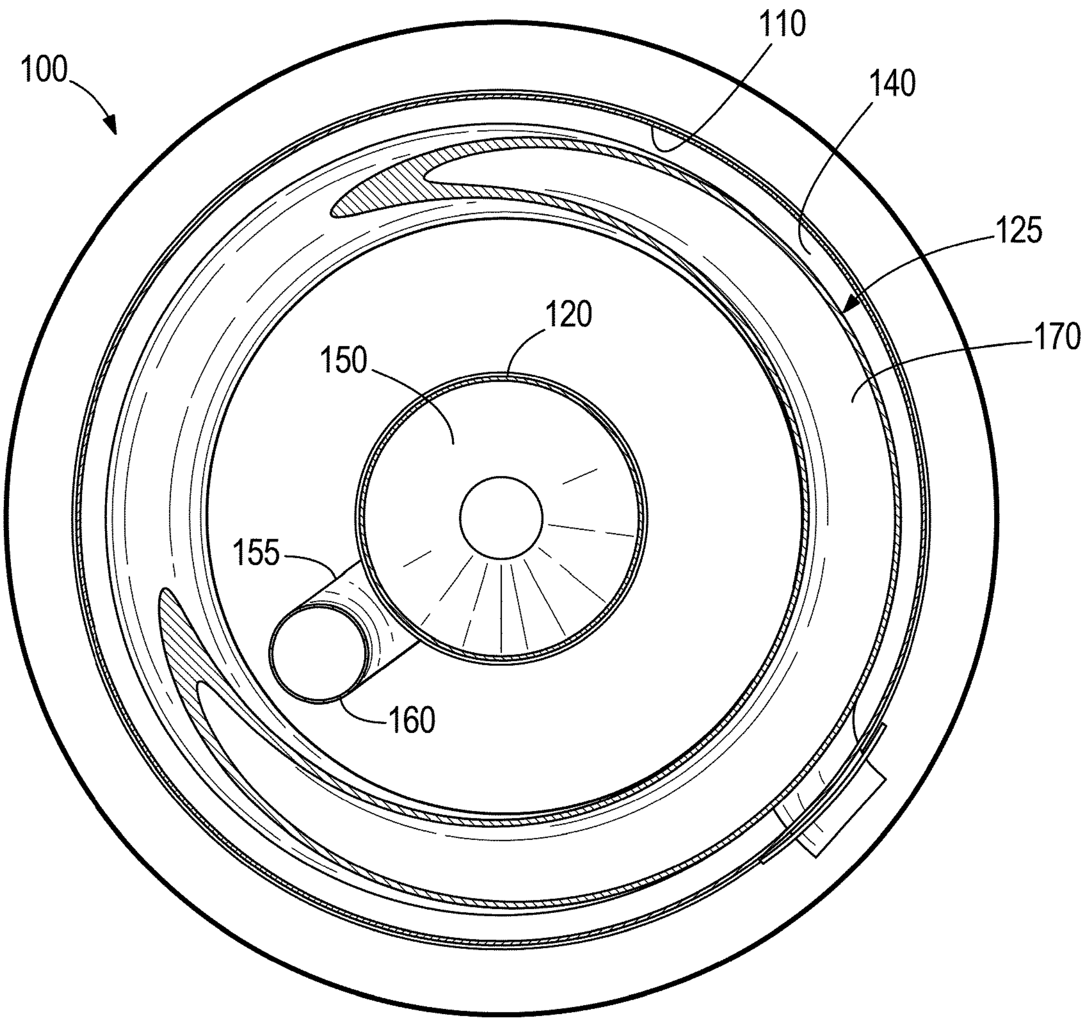

FIG. 2

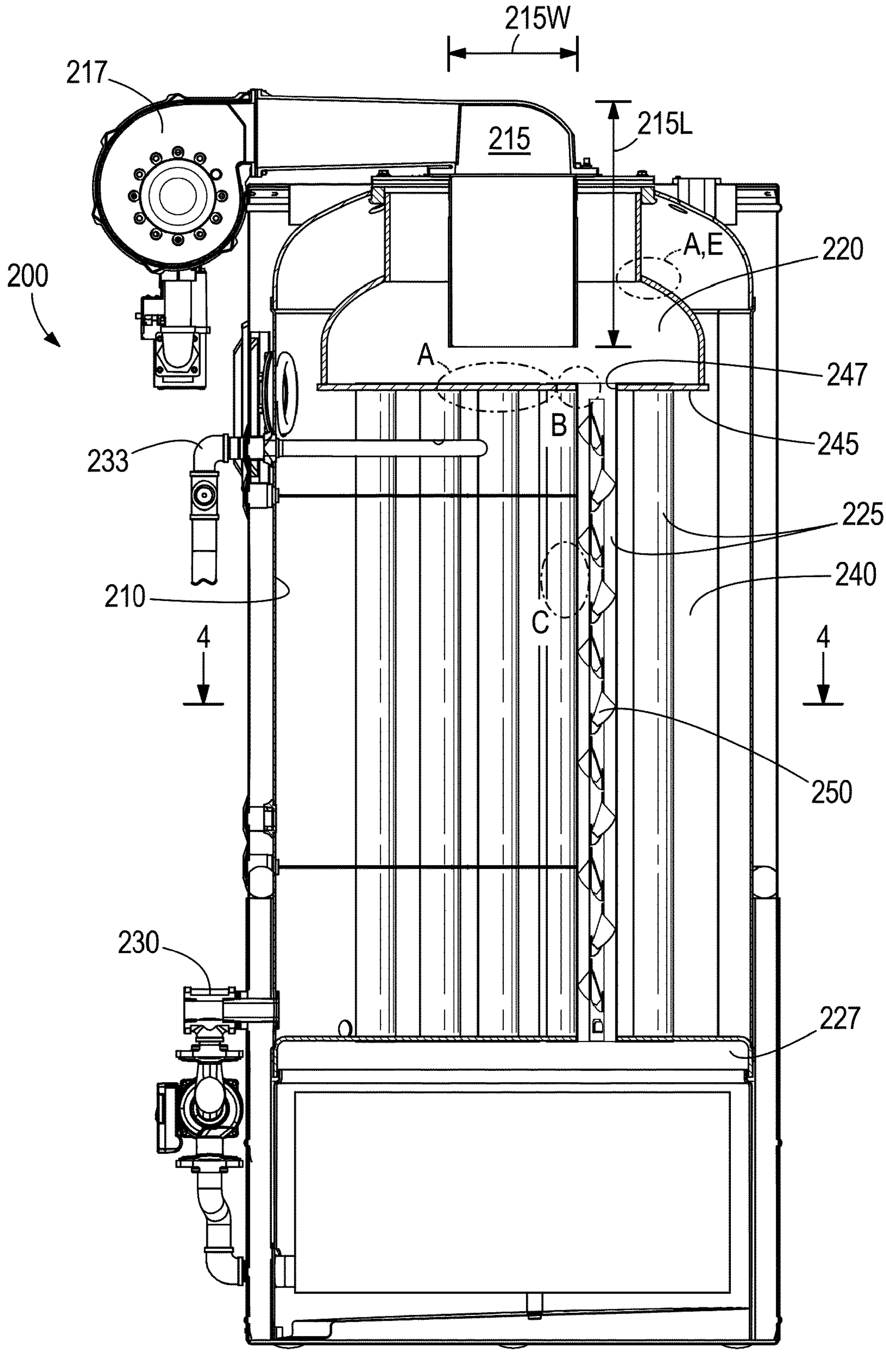
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FIG. 3

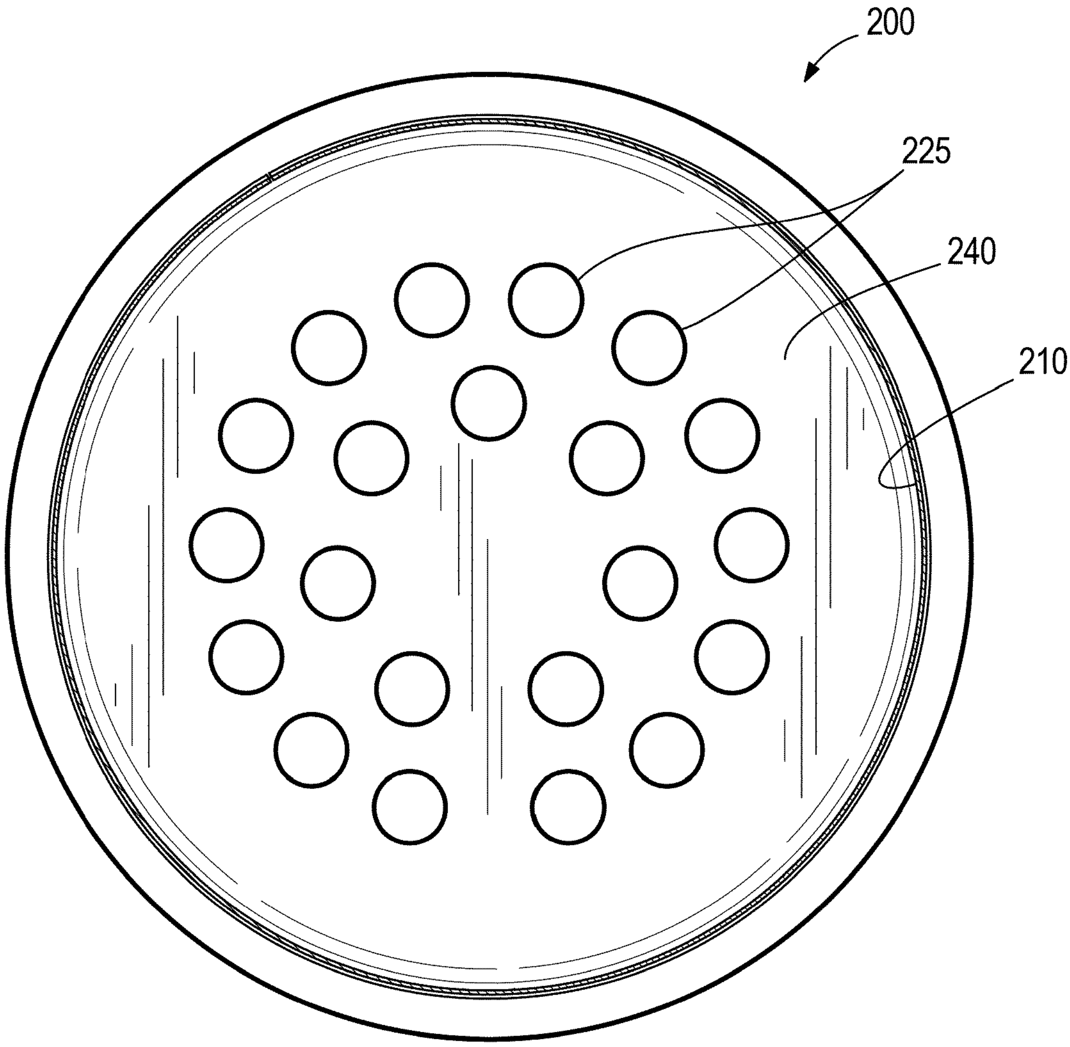

FIG. 4

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EUROPEAN SEARCH REPORT

Application Number
EP 18 18 6103

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	US 2012/291719 A1 (STEINHAFEL MICHAEL B [US]) 22 November 2012 (2012-11-22) * paragraph [0018] - paragraph [0032]; figure 1 *	1-4,6, 8-20	INV. F24H9/00
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TECHNICAL FIELDS SEARCHED (IPC)

F24H

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	17 December 2018	Riesen, Jörg

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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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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