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Hapgood

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[54] **HEAT TRANSFER STRUCTURE**

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Related U.S. Application Data

[62] Division of Ser. No. 177,024, Sept. 1, 1971.

[52] **U.S. Cl.** .... **122/235 R,** 122/367 R, 122/367 PF

[51] **Int. Cl.** **F27b 25/00**

[58] **Field of Search** ..... 122/367 R, 367 C, 367 PF, 122/250, 235

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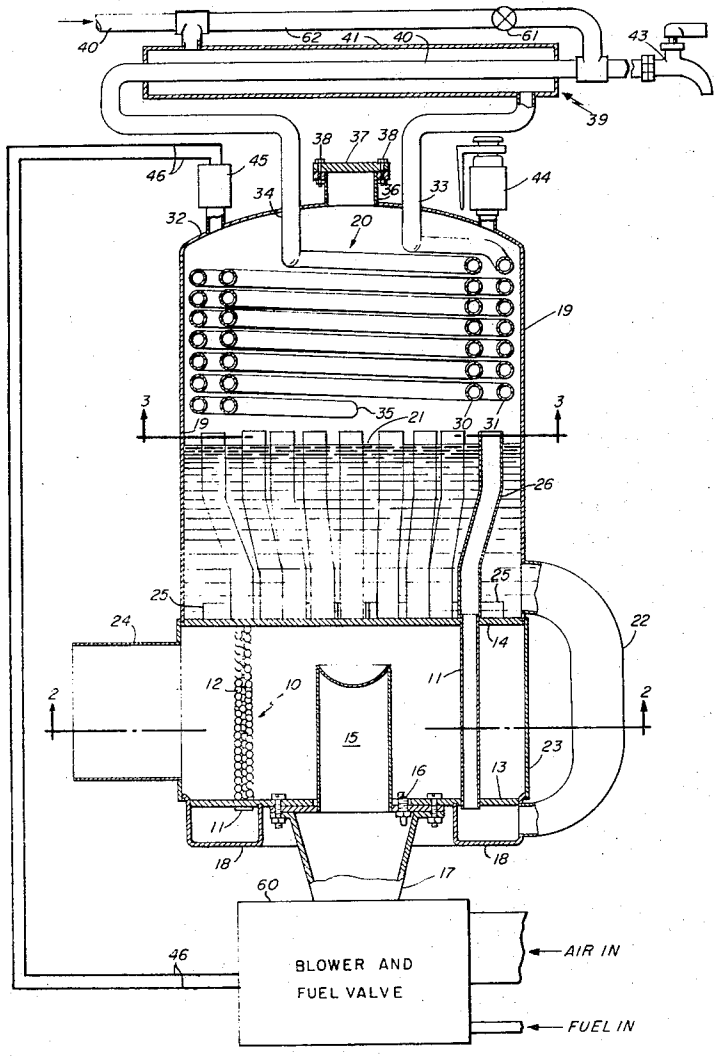
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[57] **ABSTRACT**

A heat transfer system in which circulation of a liquid through a heat exchanger is achieved by having risers filled with fluid consisting of a liquid which partly vaporizes on heating and rises to a condensing region where a heat exchanger, positioned in close proximity to the upper ends of the risers, condenses the vapor portion of the fluid. A downcomer returns the condensed liquid to the lower ends of the risers so that continuous circulation of the fluid through the heat exchanger occurs automatically when heat is supplied to the risers.

10 Claims, 3 Drawing Figures



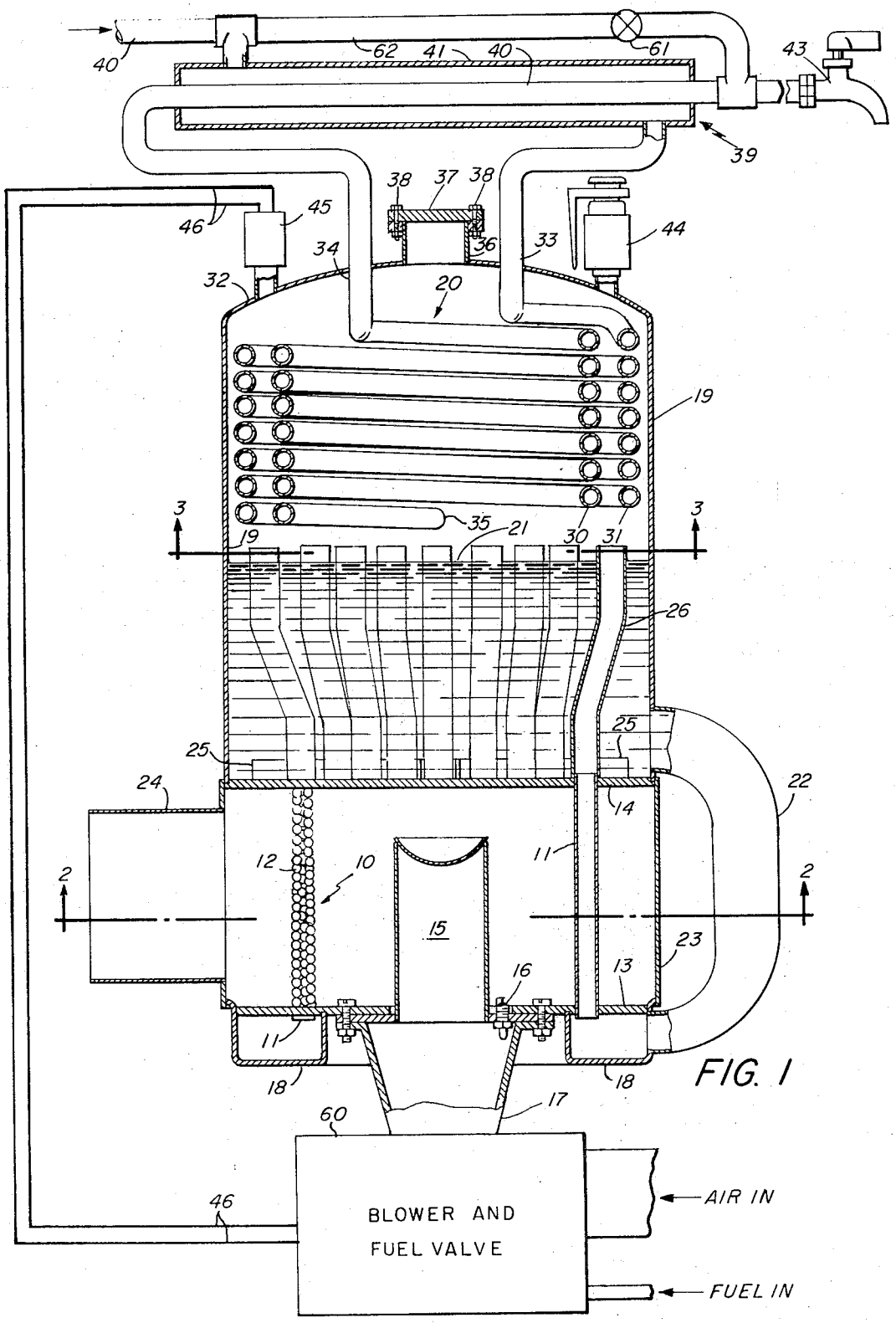

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FIG. 1

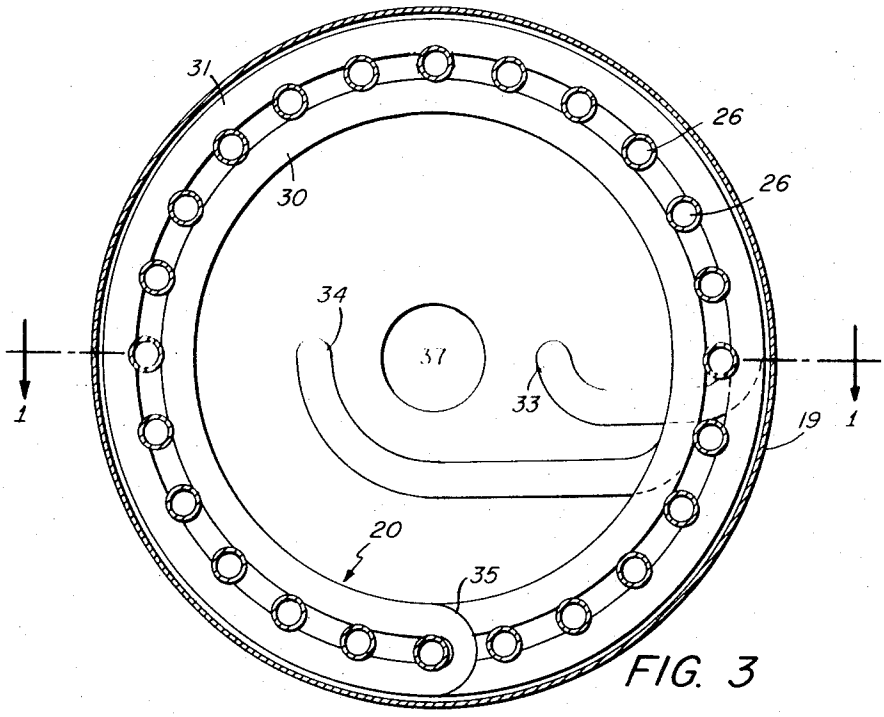


FIG. 3

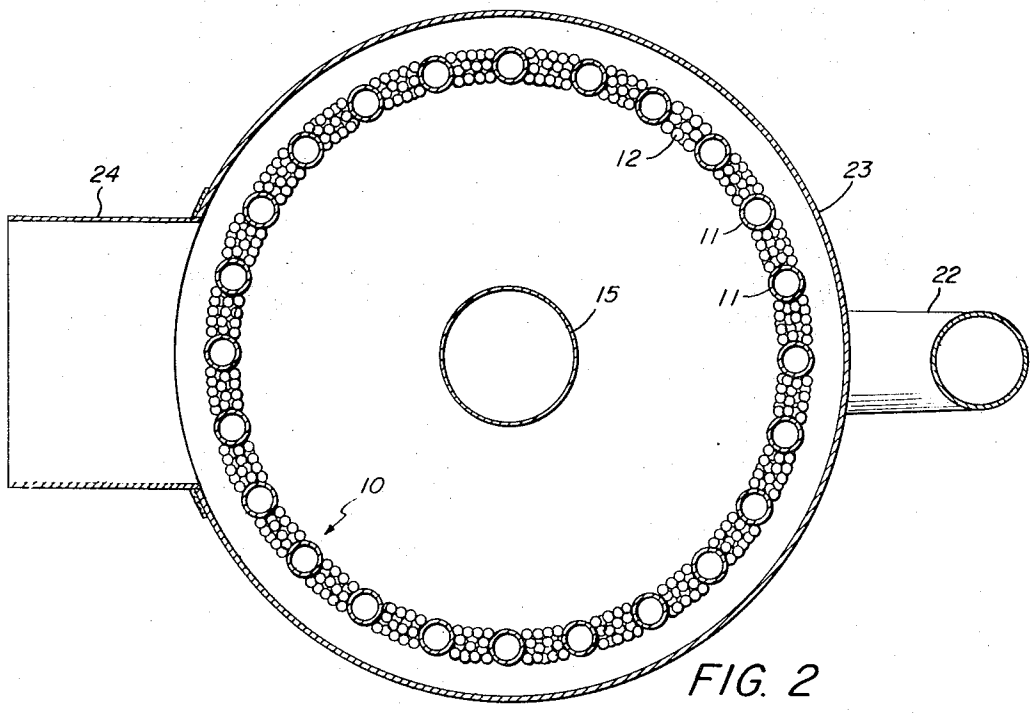


FIG. 2

HEAT TRANSFER STRUCTURE

This is a division of application Ser. No. 177,024 filed Sept. 1, 1971.

RELATED CASES

Raytheon case 28,067, Ser. No. 10,334, U.S. Pat. No. 3,704,748 entitled Heat Transfer Structure, inventor William H. Hapgood, filed Feb. 11, 1970, and assigned to the same assignee as this invention, is hereby incorporated in and made a part of this disclosure.

BACKGROUND OF THE INVENTION

High performance boilers or hot water heaters having, for example, heat exchange rates of fifty thousand to several million BTU's per square foot of water surface require that the fluid, to which the heat is being added, move by the surface of the heat exchanger at substantial speeds so that bubbles do not form at the heat exchanger surface which inhibit the transfer of heat, create hot spots, and possibly damage the heat exchanger. Bubble forming is controlled to some extent by pressure on the fluid, but the required movement of the liquid has, as illustrated in the aforementioned copending patent application, used a circulating pump to obtain the necessary rate of fluid movement.

Circulation through a boiler has been produced by allowing steam to vaporize from the boiler and be condensed in an external radiator so that the liquid produces a head due to the elevation of the radiator above the boiler which forces the condensate back into the boiler. It is necessary, however, in high performance boilers to direct each pound of liquid through the heat exchanger several times to produce a pound of steam. It is also known that steaming drums may be constructed with risers and downcomers for industrial boilers of substantial size in which the water being boiled rises into the steaming drum and is to some extent converted to steam, with the liquid portion being returned through the downcomer to the boiler. However, total liquid circulation in such a system is inadequate for compact high performance boilers.

SUMMARY OF THE INVENTION

In accordance with this invention, the liquid circulation rate through the compact boiler is automatically maintained at a sufficiently high rate to absorb all of the heat being added to the liquid by the heat exchanger. In addition, the circulation rate varies automatically as a function of the heat added.

More specifically, this invention provides for risers comprising a plurality of substantially vertical tube sections, the lower portions of which are part of a heat exchanger through which heat is added to a liquid fed to the bottoms of the risers.

Heat is not added to the upper portions of the risers, but a heat absorbing region, such as a condenser, is positioned directly above the open upper ends of the risers. The liquid in the risers will partially vaporize when heated, thereby producing gas bubbles in the upper portions of the risers. The bubbles expand as they rise since the hydraulic pressure of the fluid reduces as the fluid moves up the riser, thereby supplying energy to the fluid in the form of a velocity increase. Also, since the fluid in the riser weighs substantially less than the total weight of the fluid in a downcomer supplying liquid to the bottoms of the risers, the fluid circulates

through the risers upwardly to a condenser, and the condensed liquid is returned to the bottom of the risers in liquid form through the downcomer.

In accordance with this invention, the region around the upper portions of the risers may constitute a water reservoir to which the condensate from the condenser, positioned above the risers, is returned. The condensate mixes with the portions of the water overflowing from the tops of the risers such that the water in the downcomers is at a uniform temperature. The circulation of the water through the risers absorbs heat from the heat exchanger at a rate dependent on the flow of heat through the heat exchanger, and as the rate of heat transfer is increased, the rate at which water circulates through the risers increases since as the amount of gas increases in the upper portions of the risers, static head differential between the risers and the down-comer increases. In addition, due to steam generation in the risers, the velocity of the steam-water mixture at the tops of the risers may exceed 20 feet/second, and this aids in heat transfer to the condenser.

This invention further discloses that the system may have the liquid in the risers sealed in a closed system. As a result, the condenser may be positioned substantially directly over the risers, that is, in the highest portion of the boiler, and corrosion of the condenser is eliminated since in vented systems, when the boiler cools down, air or other corrosive atmospheres will enter the vent and accumulate in the upper, or non liquid filled, regions of the system and, upon reheating, subject the exposed portions of the boiler and/or condenser to corrosion.

This invention further discloses a control system in which the burner supplying fuel to the boiler is controlled by steam pressure in the steam dome containing the condenser. The boiler is thus always maintained at a temperature above that at which substantial condensate would form in the burner portions of the boiler, thereby reducing corrosion on the flue gas side of the heat exchanger.

This invention further discloses that such a system may be used as a hot water heater and, due to the heat reservoir of the heat stored in the boiler and in the water reservoir surrounding the risers above the boiler, cycle time is increased. For example, if only a small amount of water is drawn through a water heating coil which acts as the condenser above the boiler, the burner will not start since there is sufficient heat in the reservoir to supply this heat. On the other hand, if the amount of hot water required becomes substantial, energy can be supplied by means of the burner at as high a rate as the hot water is used. In addition, since the water emerging from the condenser is at or about boiling, this invention discloses that it may be reduced by a supplementary heat exchanger in which incoming cold water extracts a predetermined amount of heat from the exit water, and the amount that is extracted may be adjusted by a crossover valve to adjust the temperature of the exit water.

DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a longitudinal sectional view of a burner-boiler-condenser system embodying the invention taken along line 1—1 of FIG. 3.

FIG. 2 illustrates a transverse sectional view of the system illustrated in FIG. 1 taken along line 2—2 of FIG. 1.

FIG. 3 illustrates a transverse sectional view of the condenser and risers taken along line 3—3 of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIGS. 1, 2 and 3, there is shown a boiler particularly useful as a domestic or commercial hot water heater. The boiler comprises a heat exchange matrix 10 comprising a plurality of tube sections 11 which may be, for example, one-half inch or so in diameter and may be, for example, made of copper plated steel. As illustrated herein, the tube sections 11 are 5 inches or so long and are spaced in a cylindrical locus. While any number of tubes may be used, the particular embodiment disclosed herein has 24 tubes, with the spacing between adjacent tubes being somewhat less than the diameter of the tubes.

The spaces between the tubes 11 are filled with bodies 12 which, as illustrated herein, are spheres which have a diameter less than the radius of the tubes. While a substantial range of sphere diameters will provide useful results, the radius, and number of layers, of the spheres 12 is preferably such that the average length of the passageways through the spheres from the interior of the cylinder defined by the matrix 10 to the outside thereof is less than twenty times the average radius of curvature of the bodies 12, and there is more than one layer of bodies 12.

The spheres 12, which may be, for example, copper plated steel, are bonded together and to tubes 11 by positioning the spheres and the tubes in a jig and heating the assembly to brazing temperature in an oven. In order that the passageways through the spheres are not blocked, the thickness of the copper coating or a brazing compound should be such that the fillets produced during brazing have a surface area on the surface of the spheres which are essentially disc-shaped regions whose radius is in the range of one-fourth to one-tenth the diameter of the spheres. It should be clearly understood that the size of the spheres may be made larger and the total area of the contact regions between spheres may be increased while still maintaining adequate passage size. On the other hand, if the spheres are made too small, insufficient contact between adjacent spheres occurs if the copper coating of the spheres is made thin enough to maintain any substantial passageways and as a result, heat transfer by conduction between spheres becomes insufficient.

While it is to be clearly understood that other designs for producing high performance heat exchangers may be used, the ball matrix heat exchanger disclosed herein provides a commercially feasible thermally stable structure which can be subjected to combustion temperature gases.

A lower tube sheet 13 and an upper tube sheet 14 are brazed to matrix 10 such that the tubes 11 extend through apertures in the header plates and are sealed thereto. As illustrated herein, the matrix 10 surrounds an inner plenum which is six to eight inches in diameter and five inches or so in height.

Positioned in the plenum is a burner 15 which comprises a screen having apertures therein. A fuel-air mixture is supplied to the plenum through the apertures in the screen 15 from a tapered extension 17 which is supplied by means of a blower (not shown) with said fuel-air mixture. Ignition of the fuel-air mixture in the plenum is achieved by means of ignition plug 16. Such a system is disclosed in greater detail in the aforementioned copending application. It should be understood that any conventional burner system could be used, such as a conventional oil burner or a gas burner.

Attached to the lower side of lower tube sheet 13 is a toroidal plenum 18 which may be provided internally with suitable baffling to evenly distribute water or other liquid to be heated to the lower ends of the tubes 11. Connected to the upper side of upper tube sheet 14 is a steam dome 19 which serves the dual purpose of enclosing a water-steam heat exchange coil 20 and acting as a reservoir for liquid 21 to be heated. A recirculating pipe 22, referred to as a downcomer, is connected from the region of dome 19 below the surface of liquid 21 to plenum 18. Pipe 22 is substantially larger in diameter than the tubes 11, being for example one and one-half inches in diameter. Its total cross-sectional area, however, should preferably be sufficient to present no substantial impedance to the flow of the liquid and, as shown herein, is substantially less than the total cross-sectional area of all of the tubes 11, said total cross-sectional area of the tubes being, for example, somewhat more than four square inches, whereas the total cross-sectional area of connector 22 is around two square inches. This is because the pipe 22 is completely full of liquid at all times during operation, whereas the tubes 11, which form the portions of risers through which the water rises upon being heated, are at least partially filled with steam.

The outer rims of tube sheets 13 and 14 are closed by a cylindrical stack member 23 which has an outlet stack 24 connected to one side thereof.

Dome 19, which as illustrated herein is approximately twice the height of the matrix 10, has the lower portion thereof preferably filled with a reserve supply of water or other fluid, such as ethylene glycol or other antifreeze. In order to stiffen tube sheet 14, stiffening ribs 25 may, if desired, be welded to the upper side of tube sheet 14.

Extending upwardly from the ends of tubes 11 which project through upper tube sheet 14 are riser extension tubes 26. As illustrated herein, pipes 26 may be, for example, equal to, or shown herein, slightly bigger in diameter than tubes 11 so that they closely fit over the ends of tubes 11, the assembly of a tube 11 and tube 26 being referred to herein as a riser. The surface of liquid 21 is preferably maintained at or about the upper ends of the tubes 26.

During operation, the fuel-air mixture produces flue gas products by combustion in the central plenum of the matrix 10, and such products are directed radially outwardly through matrix 10 to an outer plenum formed by the cylinder 23 and thence via flue 24 to a chimney (not shown). Heat from the flue gas is transferred via matrix 10 to the fluid in the tubes 11. The fluid will rise since it is less dense than the cooler liquid in the downcomer pipe 22, and the water will overflow the ends of the tubes 26.

Even if the liquid level 21 is so far below the tops of the pipes 26 that the differential of the weight of the hot water in the tubes 26 and the cold water in tubes 22 will not produce a height differential sufficient for the water to overflow the ends of the tubes 26, the heating will continue until vapor bubbles are formed within the tubes 11, whereupon the bubbles in the vapor rise and expand, carrying portions of the liquid

with them thereby producing a "gas lift" pumping mode of operation which can exert a force on the fluid substantially greater than a pressure head equal to the length of tubes **26.** Thus, it may be seen that by properly designing the length of the tubes **26,** a continuous circulation of fluid through the tubes **11** may be maintained and that the rate of the circulation will vary automatically with the amount of heat being transferred by the burner **15** to the matrix **10.**

Positioned in dome **19** above the ends of pipes **26** is a double helical coil which may comprise, for example, an inner coil **30** and an outer coil **31** positioned with the axes of the coils coaxial with the axis of the matrix **10.** The coils may be, for example, seven turns of half inch tubing formed, for example, of copper. As illustrated herein, one end of the tubing coil **31** extends through the upper end **32** of the dome **19,** as indicated at **33,** and is sealed therethrough, for example by brazing. End **33** may be, for example, a cold water inlet pipe for use in a water system to be described presently. One end of the inner tubing coil **30** extends outwardly through dome top **32** as at **34** and is sealed to dome top **32** to provide a hot water outlet. As illustrated herein, cold water enters the upper end **33** of outer coil **31** and spirals down to the lower end of the coil where it crosses as at **35** to the inner coil **30** and spirals up inner coil **30** to connect to the outlet end **34.** The space between the inner and outer coils is approximately the diameter of the riser tube extensions **26** whose upper ends are positioned closely adjacent and between coils **30** and **31.** When the matrix **10** heats the tubes **11,** a steam-water mixture rises through the tubes **26** and sprays up between the coils **30** and **31.** Sufficient heat transfer is achieved by reason of condensation of the steam on the tubing coils **30** and **31** to transfer all of the heat, being supplied by the burner **15** to the matrix **10,** into the water in heat exchanger **20.** Because the heat exchange action is the result of the condensation process on the walls of the tubing **20,** very high heat transfer coefficients result, and hence no fin structure is required to produce the same total heat exchange in this region as was required to exchange heat from the flue gas to the liquid in the matrix **10.**

A safety valve **44** is provided which is normally set to open at fifteen pounds pressure, but may, if desired, be set to open at a higher or a lower pressure.

If desired, steam may be extracted from the boiler for other uses by means of a pipe **36** connected to the upper end of the dome **32.** However, as shown here, pipe **36** is closed by a plate **37** bolted to pipe **36** by bolts **38.**

In order to provide for control of the burner, a pressure sensing switch **45** is connected to dome header **32** to provide a plurality of wires **46,** which control a blower-fuel valve assembly **60** which may be of any desired type. The pressure sensing switch is of the type which opens when the pressure reaches a predetermined level and for purposes of this invention may be set to operate at a pressure of, for example, 5 pounds.

As illustrated herein, the water heater operates as a closed system; the air in the system having been, for example, initially removed by momentarily releasing the safety valve. Since the system is a closed system, that is, the only fluid flowing through the matrix tubes **11** and risers **26** and impinging on the heat exchange coil **20** is the liquid or the vapor of the liquid, this fluid may be selected to be noncorrosive.

More specifically, the liquid may be distilled water or it may be a mixture of water and ethylene glycol or ethylene glycol with a corrosion inhibitor added. Since the temperature of the heat exchanger tubes **11** does not exceed the thermal decomposition temperature of the corrosion inhibitor, the corrosion inhibitor will remain intact so that no corrosion occurs within the system. In addition, the water in tubing **20** is maintained below its boiling point and, hence, will not have vapor formed therein. More specifically, since the pressure in a normal water system of, for example, 50 to 100 pounds per square inch, will exist inside the tubing **20** and the steam on the outside of the tubing **20** will be less than 15 pounds, the temperature within the tubing **20** will never be high enough for the water to turn to steam.

The water heater of this invention will heat the water in the heat exchanger coil **20** to a temperature limited by the temperature of the steam in the steam dome. The rate at which the water is heated will be substantially greater than the rate at which water could be heated by immersing the heat exchanger **20** in the water beneath the coil since the pumping action produced by the riser tubes will spray steam and a steam-water mixture from the ends of the tubes at a velocity on the order of twenty feet per second.

It is contemplated that liquids other than water can be used in this system to be heated by the matrix **10** and that due to the particularly uniform heat distribution afforded by the structure described in this invention, fluids, such as organics, which might be damaged by localized hotspots can be used with this heat exchanger without risk of damage or deterioration.

The water heated by the heat exchanger **20** will be too hot at its output for most applications, particularly if the flow rate is relatively low. However, for installations such as a home water heater, the piping from the water heater to the faucet where the water is to be used will introduce thermal losses, and the length of the piping, as well as the ambient temperature and insulating conditions of the pipe, will affect the temperature. Since this water heater will supply the substantially uniform temperature of water from the output of the heater, it is possible to compensate for losses in the piping and rates of flow of water through the heat exchanger to maintain a more uniform temperature of water at the faucet. This is different from a conventional water heater having a tank in which, as the water is used and replaced in the tank by colder water, the average temperature of the water at the faucet decreases.

In order to compensate for changes in temperature with varying hot water use, a liquid to liquid heat exchanger **39** is provided external to the dome **19** and through which the cold inlet water and the heated outlet water pass. Some of the heat from the outlet water passes through the heat exchanger **39** to the inlet water, the amount of heat being exchanged being dependent upon the flow of water through the heat exchanger. If, for example, it is desired that the hot water heater add 100° to the water such that the outlet water is at 170°, whereas the cold water inlet is at 70°, approximately 100 BTU's per pound of water must be added. Thus, if 25 pounds per minute of water is to be used, or, for example, 3 or 4 gallons per minute for washing or other such purposes, the unit needs to supply a total of 2,500 BTU's per minute to the heat exchanger **20** or approximately 150,000 BTU's per hour. If no water is being

drawn and there were no losses in the connecting tubing, an external heat exchanger would cause the temperature of the inlet water to rise so that it exactly equaled the outlet water. Thus, if the outlet water were 210° and the inlet water were 70°, the water supplied to the outlet of the external heat exchanger would be 140°. However, as soon as the hot water faucet, indicated at **43**, is opened to extract hot water, flow through the external heat exchanger **39** begins. Under these conditions, the water outlet from the heat exchanger **20** would drop, for example, by a few degrees due to the temperature drop across the heat exchanger to, for example, 200°. The heat transferred by the heat exchanger for relatively low flows can be designed to be relatively small and results in the 200° water from the boiler being reduced to, for example, 170° at the faucet **43**. The inlet water to the boiler, on the other hand, would be increased to 100° so that by adding 100 BTU's per pound in the heat exchanger **20**, the outlet water becomes the 200° F. water referred to above.

Heat exchanger **39** is shown as a pair of concentric pipes, the inner pipe **40** being connected from the outlet of the heat exchanger **20** to the faucet **43** and being, for example, half inch copper tubing. The outer concentric pipe **41** is connected between a source of cold water and the inlet end of tubing **20**. The ends of the outer pipe **41** are sealed to the outside of the tube **40**, thereby forming the concentric heat exchanger. The length of the heat exchanger comprising elements **40** and **41** is determined by the amount of heat to be transferred therethrough for a given flow of water.

It has been found that the coefficient of heat transfer of such a heat exchanger is less for lower flows of water than for higher flows of water, and advantage is taken of this feature to compensate for any temperature changes which occur due to varying flows at the faucet **43**. Thus, as the flow through the heat exchanger increases, the coefficient of heat transfer increases so that the total heat transferred increases as a non-linear function of the velocity of the water through the heat exchanger. In addition, heat lost by radiation from the pipe connected between the water heater and the faucet is generally proportional to the temperature of the pipe and substantially independent of the total heat energy transferred along the pipe by the hot water and, therefore, the percentage of heat in the water which is lost by radiation from the pipe becomes less as the flow rate increases. This invention discloses that the temperature of the water in the faucet may be maintained more closely within a predetermined range of temperatures over a wide range of flow rates by using the external heat exchanger **39** to compensate for the faucet water temperature with increased flow rate which would occur in the absence of the heat exchanger **19**. This results from the fact that as the flow rate is increased so that a lower percentage of heat is lost from the pipe by radiation, a higher percentage of heat is transferred back to the inlet water to the water heater so that the water heater, which adds heat only up to substantially a predetermined limit of between 200° and 210°, reduces the BTU's per pound of heat which it adds to the water so that the water temperature at the outlet of the external heat exchanger **39** is also reduced, thereby slightly reducing the heat lost by radiation but resulting in substantially the same temperature at the faucet as would occur at a lower flow rate. The water temperature at faucet **43** may be adjusted by a valve **61** in a bypass pipe **62** connected between the input and outlet of heat exchanger **39**.

It is contemplated that the combination of three heat exchangers as disclosed herein, one for transferring heat from flue gas to boiler water, a second for transferring heat from a steam-water mixture to water, and a third for compensating for flow rates, can be used for many systems other than the heating of water, such as, for example, the heating of cooking oil to a uniform temperature which can be adjusted, the heating of industrial processing liquids, or the heating of water to maintain a constant temperature heat slightly below the boiling point of water to an additional gas-water heat exchanger to maintain a constant gas temperature use of the heat exchanger.

In accordance with this invention, the matrix **10** may operate at rates of heat transfer per unit area which are far in excess of such rates in commercial boilers, and the rate of circulation of fluid through the risers will automatically increase as a function of the heat transfer rate to prevent overheating of the matrix. The downcomer pipe **22** is of sufficient size that it presents no substantial resistance to the flow of the fluid. The rate at which fluid flows through the tubes **11** is a function of the elevation head supplied by the level of liquid **21** in the reservoir above matrix **10**. As more heat is supplied to the matrix **10** by the flue gas, a greater portion of the liquid in the tubes **11** is converted to steam and rises in the tube extensions to thereby create a greater head differential, thereby increasing the flow of liquid down pipe **22** to the bottoms of tubes **11**.

In addition, since the matrix **10** is a plurality of spheres, heat transfer by conduction through the matrix longitudinally along the tubes **11** dissipates any localized hot spots and insures that no portions of the matrix become sufficiently overheated to be damaged, for example by melting of the bonds.

In accordance with this invention, it is contemplated that such a structure for preventing damage to such a heat exchanger may be used in heat exchange systems for generating steam for supply to additional heat exchangers such as the water heating coil illustrated herein, as well as the supply of steam to external loads or for the supply of hot water directly from the reservoir above the heat exchanger to external loads.

This completes the description of the modifications of the invention illustrated herein. However, many modifications thereof will be apparent to persons skilled in the art without departing from the spirit and scope of this invention. For example, any desired shape of heat exchanger could be used. The source of heat could be of any desired type, such as electrical heaters, radiation heaters, or waste heat derived, for example, from electronic components, and the system could be put to any desired heat transfer use. In addition, the control system can be made to function by temperature sensing rather than pressure sensing, or a combination of both and any desired safety or limit condition switches may be used.

Accordingly, it is intended that this invention be not limited to the particular details of the embodiments disclosed herein except as defined by the appended claims.

What is claimed is:

1. A heat exchange system comprising:

a thermally conductive matrix comprising a plurality of tubular members providing a conduit for fluid to

be heated and rigidly interconnected by thermally conductive bodies which provide at least portions of the walls of a plurality of passageways for gaseous products of combustion, the total area of said passageways in said matrix being substantially greater than the total area of said conduit in said matrix;

means for supplying fluid from the upper end of said conduit to a reservoir above said matrix;

means for supplying fluid from said reservoir substantially directly to the lower end of said conduit; and

means for supplying said combustion products to said passageways to heat said matrix.

2. The heat exchange system in accordance with claim **1** wherein said matrix comprises a plurality of layers of thermally conductive bodies positioned between adjacent portions of said conduit and bonded thereto.

3. The heat exchange system in accordance with claim **2** wherein said bodies are substantially predominantly curved in all directions.

4. The heat exchange system in accordance with claim **3** wherein the average length of said passageways is not substantially greater than twenty times the average radius of curvature of the surface areas of said bodies.

5. The heat exchange system in accordance with claim **4** wherein said bodies are substantially spheroidal.

6. The heat exchange system in accordance with claim **1** wherein said tubes and bodies are bonded together to to form a substantially cylindrical matrix having a central plenum.

7. The heat exchange system in accordance with claim **6** and means for supplying heated gases to said central plenum to transfer heat to said tubes at a rate in excess of 50,000 BTU's per square foot per hour of the surface area of the interior of said tubes.

8. The heat exchange system in accordance with claim **7** wherein said means for supplying heated gases comprises a burner for supplying a fuel-air mixture to said plenum.

9. The heat exchange system in accordance with claim **8** wherein said burner comprises a foraminous structure extending into said plenum.

10. The heat exchange system in accordance with claim **9** wherein said burner is supplied with said fuel-air mixture in gaseous form by a blower.

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