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(54) LIQUID DESICCANT AIR CONDITIONER

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(60) Division of application No. 09/131,287, filed on Aug. 7, 1998, now Pat. No. 6,216,483, which is a continuation-in-part of application No. 08/984,741, filed on Dec. 4, 1997, now Pat. No. 6,138,470.

Publication Classification

(51) Int. Cl.[7] **F25D 23/00**; F25D 17/06; F25B 27/00; F25B 25/00
(52) U.S. Cl. **62/271**; 62/94; 62/238.3; 62/332

(57) **ABSTRACT**

The present invention provides a liquid desiccant air conditioner including an absorption air conditioner and a liquid desiccant dehumidifier. The dehumidifier includes a liquid desiccant absorber for absorbing moisture contained in ambient air entering the dehumidifier and passing through the desiccant absorber. A boiler is provided for boiling partially preheated dilute liquid desiccant to evaporate moisture to reconstitute the liquid desiccant into concentrated liquid desiccant. In a preferred embodiment, a first heat exchanger fluidly communicates with the desiccant absorber and a second heat exchanger. The first heat exchanger is operable to transfer heat from the concentrated liquid desiccant to the dilute liquid desiccant directed to the first heat exchanger from the desiccant absorber to raise the temperature of the dilute liquid desiccant to a first temperature. A condenser fluidly communicates with the boiler to receive steam generated by boiling the liquid desiccant in the boiler, and with the first heat exchanger to receive partially heated dilute liquid desiccant from the first heat exchanger at the first temperature. The condenser is operable to sensibly heat the dilute liquid desiccant therein to a second temperature by recovering the latent heat of condensation as steam delivered from the boiler is condensed. The second heat exchanger fluidly communicates with the condenser, the boiler and the first heat exchanger. The second heat exchanger is operable to transfer heat from concentrated liquid desiccant directed to the second heat exchanger from the boiler to the dilute liquid desiccant directed to the second heat exchanger from the condenser at the second temperature to raise the temperature of the dilute liquid desiccant to a third temperature. The dilute liquid desiccant at the third temperature is directed to the boiler and the concentrated liquid desiccant from the second heat exchanger is directed to the first heat exchanger. The second heat exchanger is disposed with respect to the boiler to recover waste heat from the boiler. A pump is provided for pumping concentrated liquid desiccant into the absorber. A fraction of the steam from the boiler is used to regenerate the refrigerant in the absorption air conditioner.

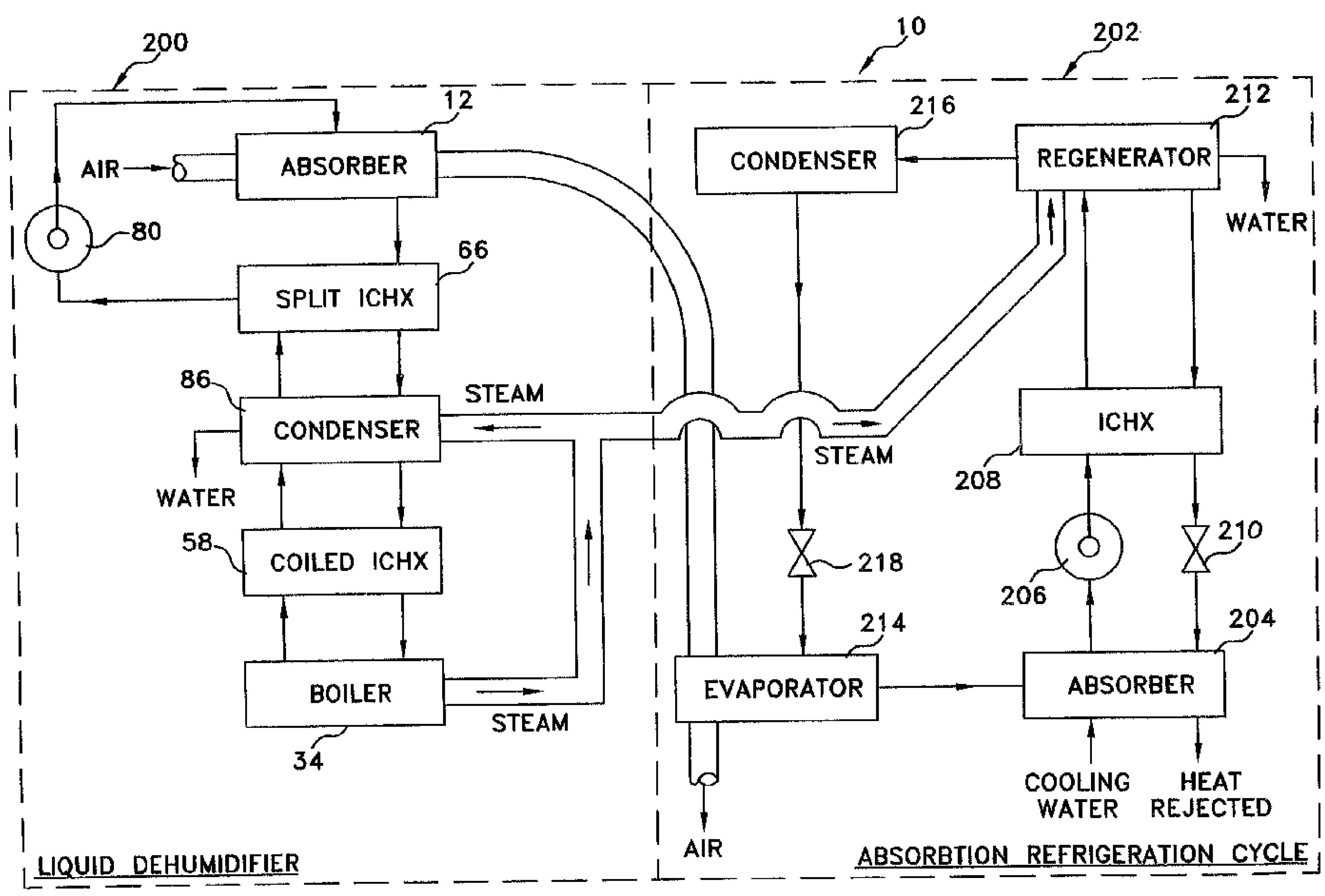
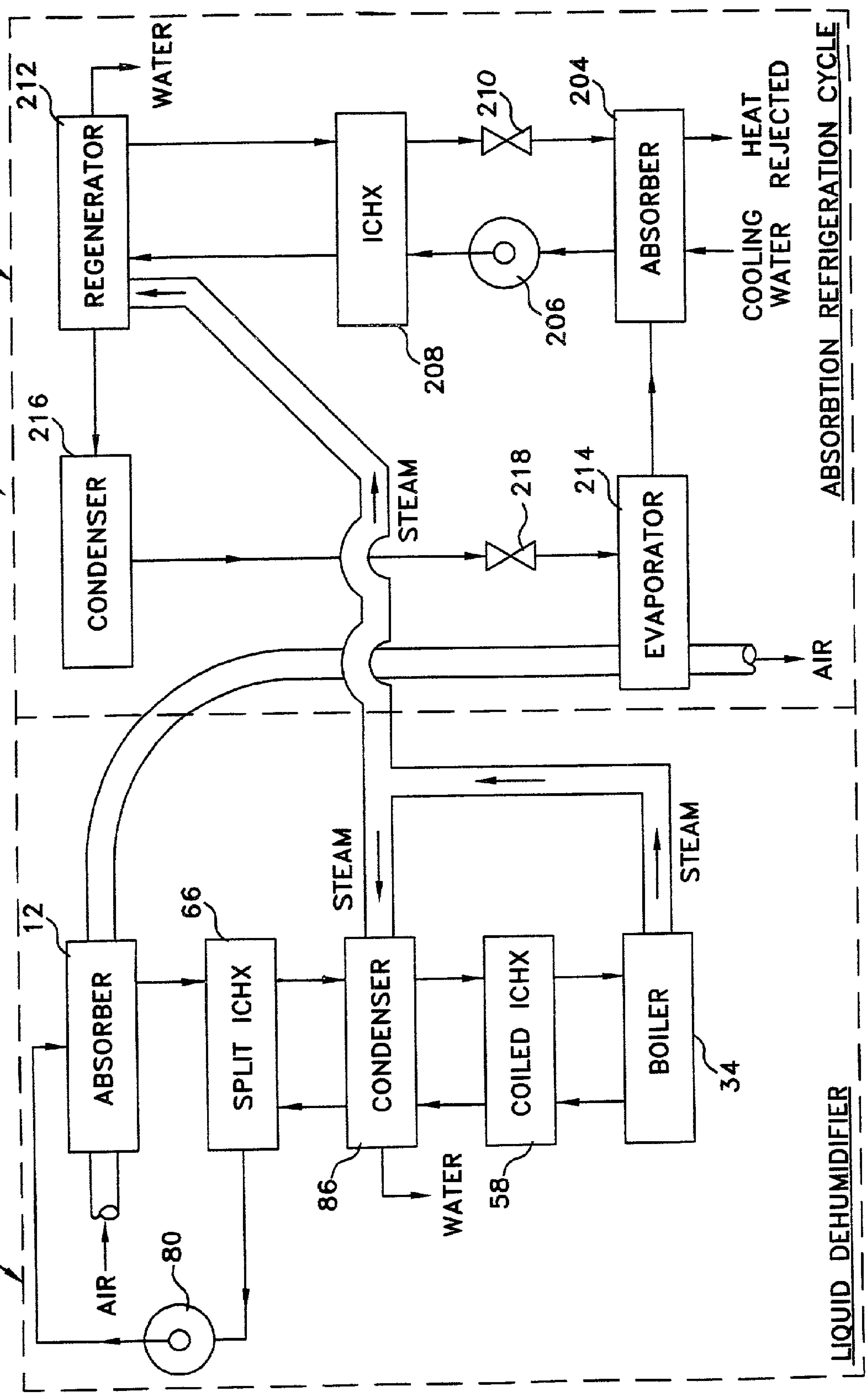
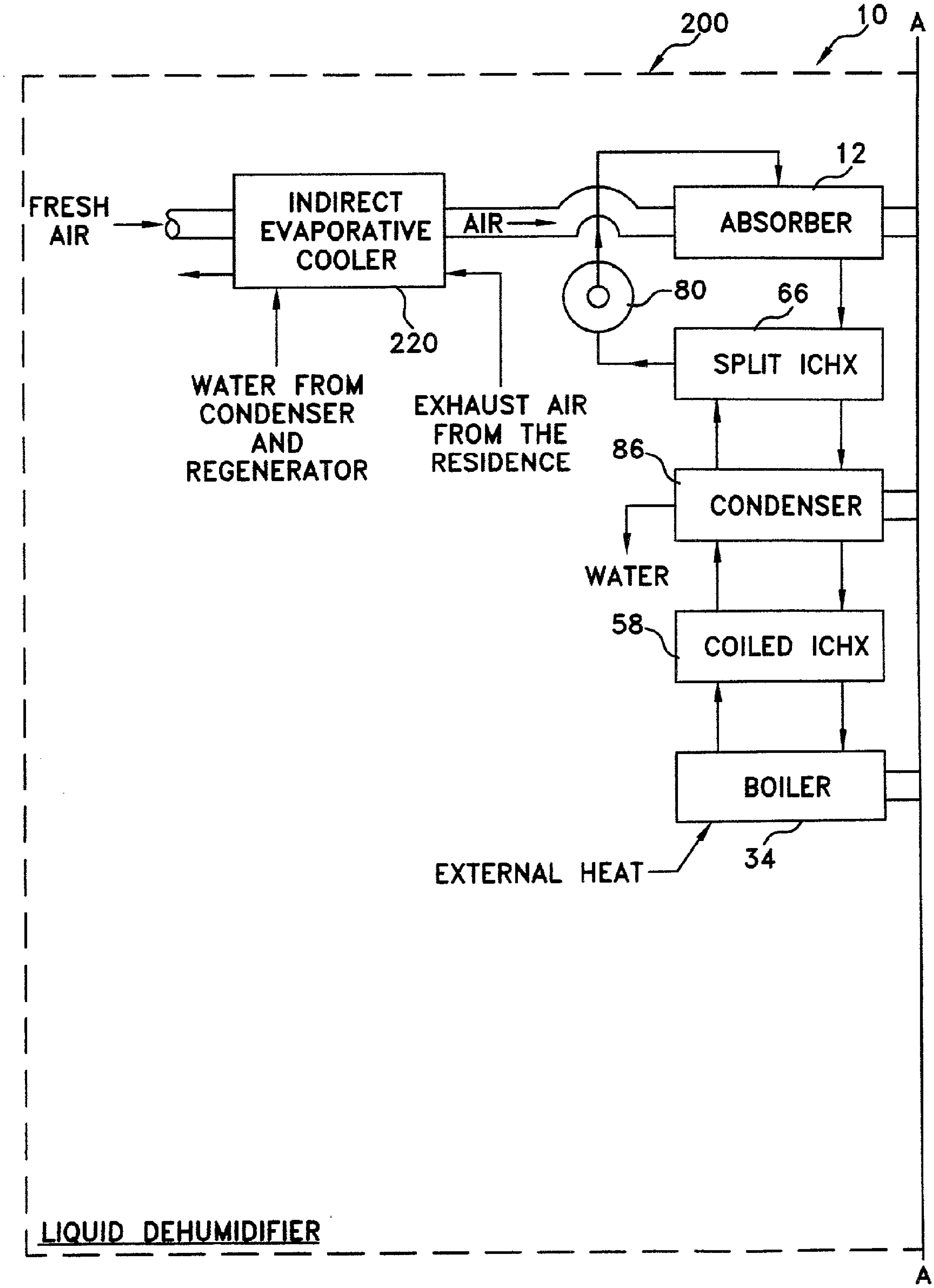


FIG. 1



10
202
200
REGENERATOR
212
WATER
ICHX
208
210
204
ABSORBER
206
HEAT
REJECTED
COOLING
WATER
ABSORBTION REFRIGERATION CYCLE
CONDENSER
216
STEAM
218
214
EVAPORATOR
AIR
ABSORBER
12
SPLIT ICHX
66
STEAM
CONDENSER
86
WATER
COILED ICHX
58
BOILER
34
STEAM
AIR
80
LIQUID DEHUMIDIFIER

FIG. 2A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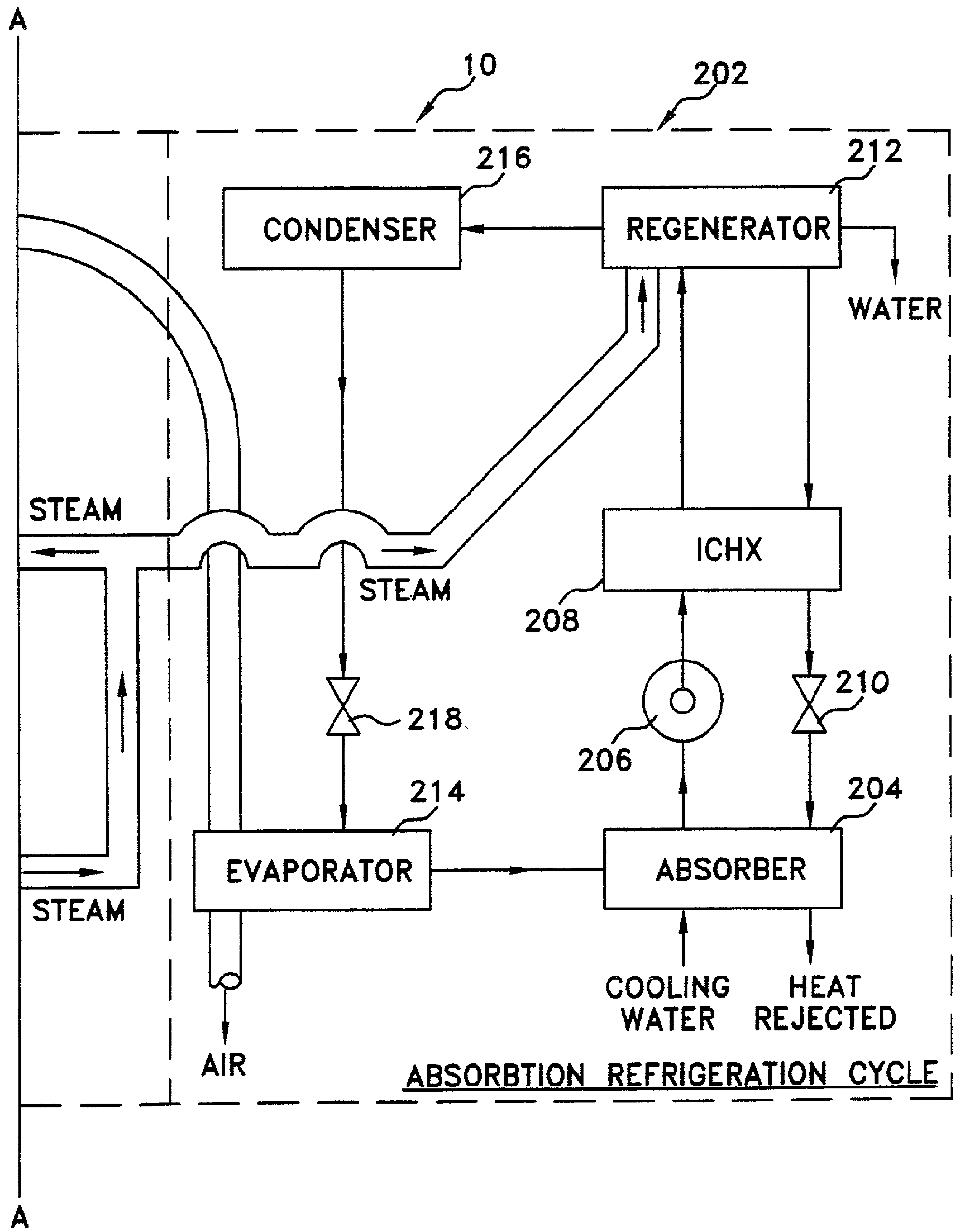
A
12
FRESH AIR
INDIRECT EVAPORATIVE COOLER
AIR
ABSORBER
80
66
220
SPLIT ICHX
WATER FROM CONDENSER AND REGENERATOR
EXHAUST AIR FROM THE RESIDENCE
86
CONDENSER
WATER
58
COILED ICHX
BOILER
EXTERNAL HEAT
34
LIQUID DEHUMIDIFIER
A

FIG. 2B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202
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WATER
STEAM
ICHX
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206
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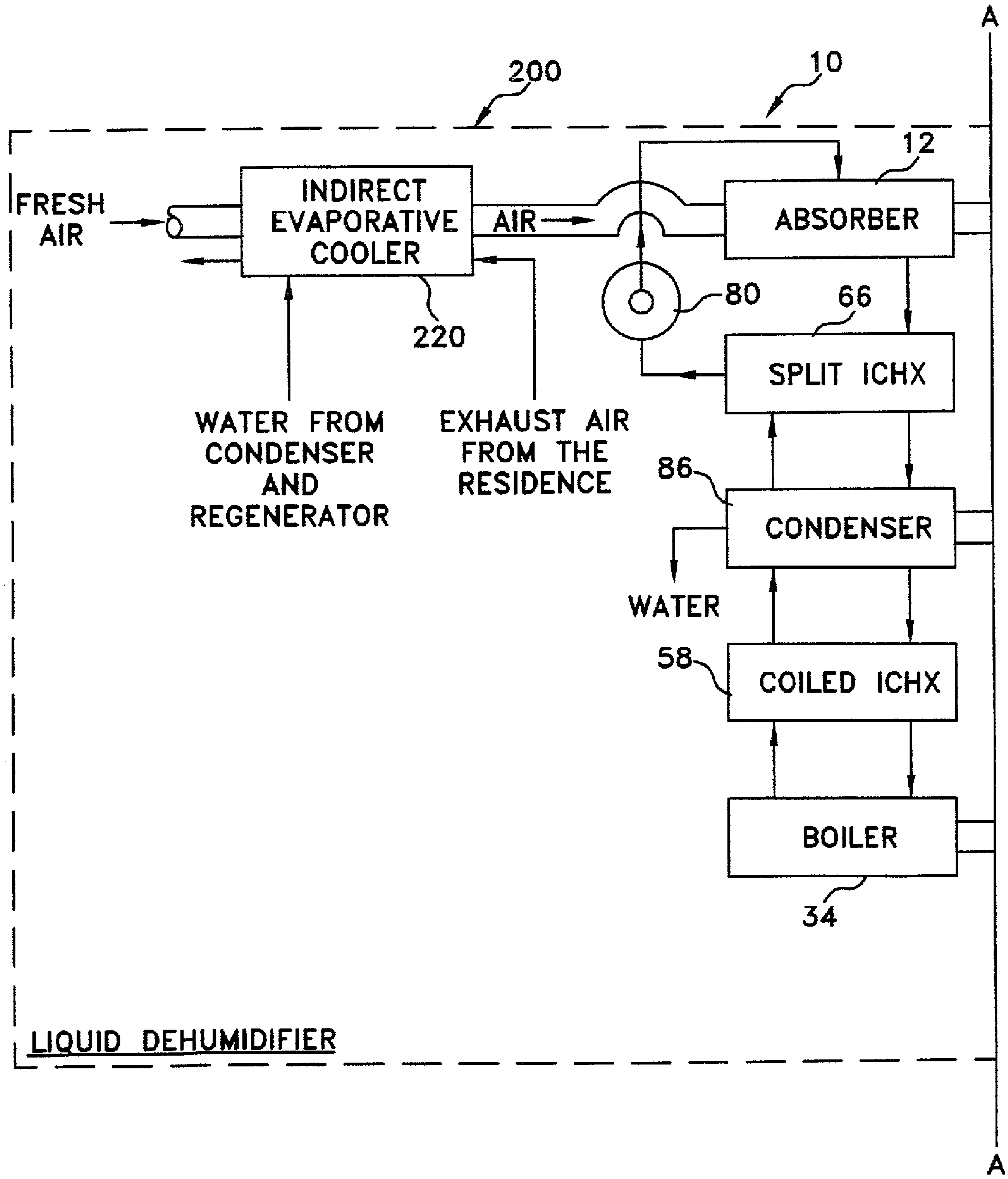
204
EVAPORATOR
ABSORBER
STEAM
COOLING
WATER
HEAT
REJECTED
AIR
ABSORBTION REFRIGERATION CYCLE
A

FIG. 3A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ABSORBER
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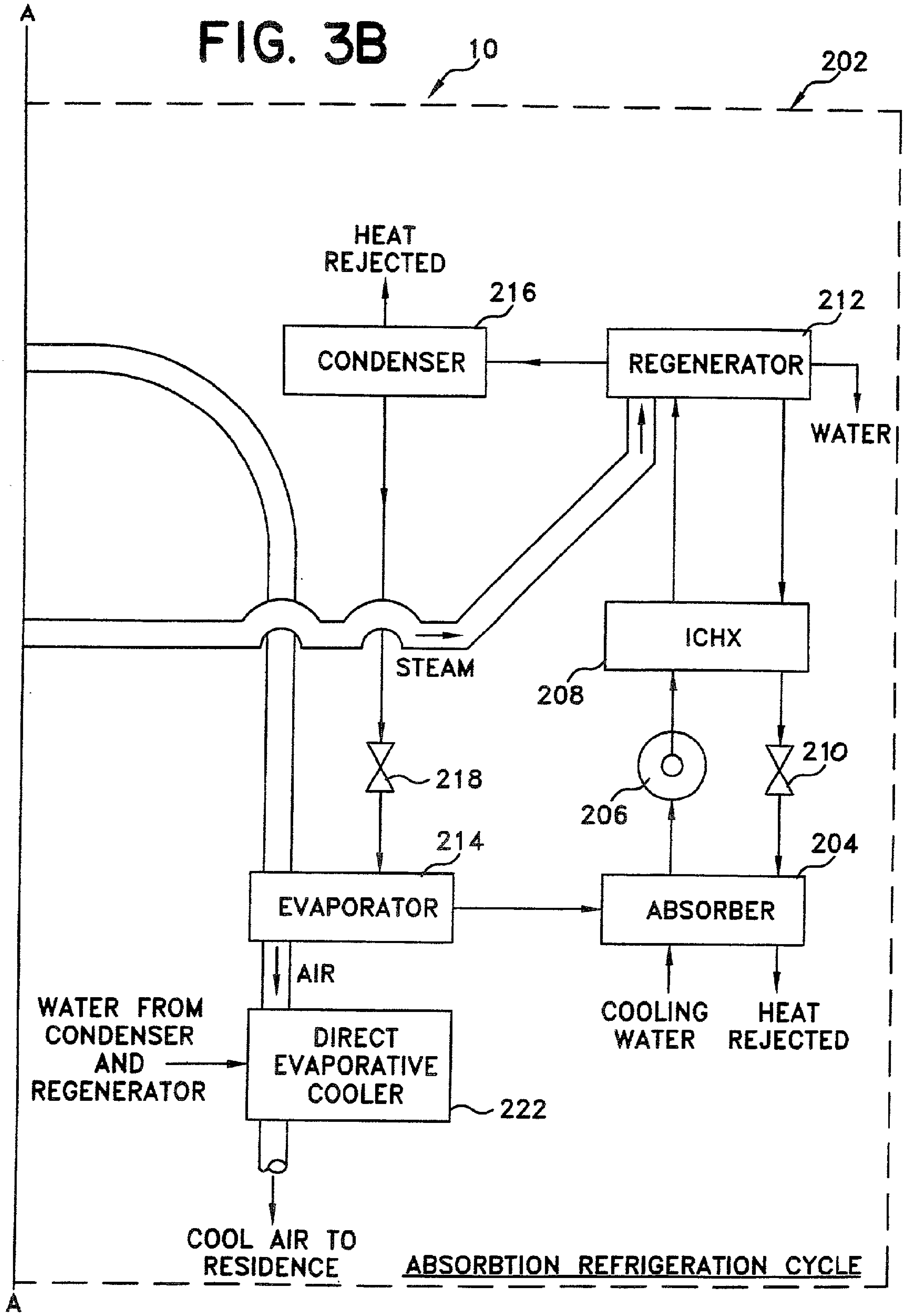
66
220
SPLIT ICHX
WATER FROM CONDENSER AND REGENERATOR
EXHAUST AIR FROM THE RESIDENCE
86
CONDENSER
WATER
58
COILED ICHX
BOILER
34
LIQUID DEHUMIDIFIER
A

FIG. 3B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HEAT
REJECTED
216
212
CONDENSER
REGENERATOR
WATER
ICHX
STEAM
208
218
210
206
214
204
EVAPORATOR
ABSORBER
AIR
WATER FROM
CONDENSER
AND
REGENERATOR
DIRECT
EVAPORATIVE
COOLER
COOLING
WATER
HEAT
REJECTED
222
COOL AIR TO
RESIDENCE
ABSORBTION REFRIGERATION CYCLE
A

FIG. 4A

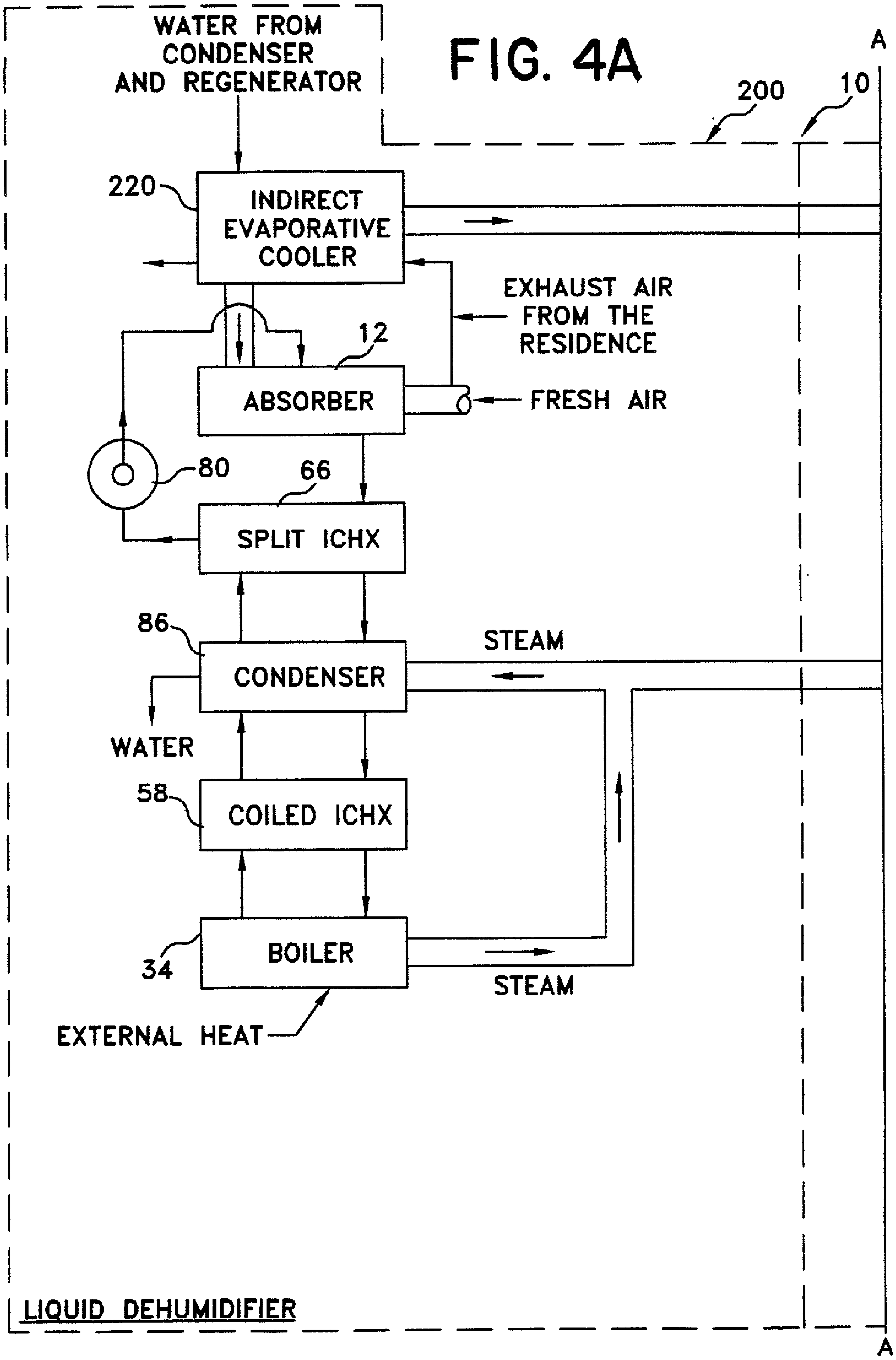
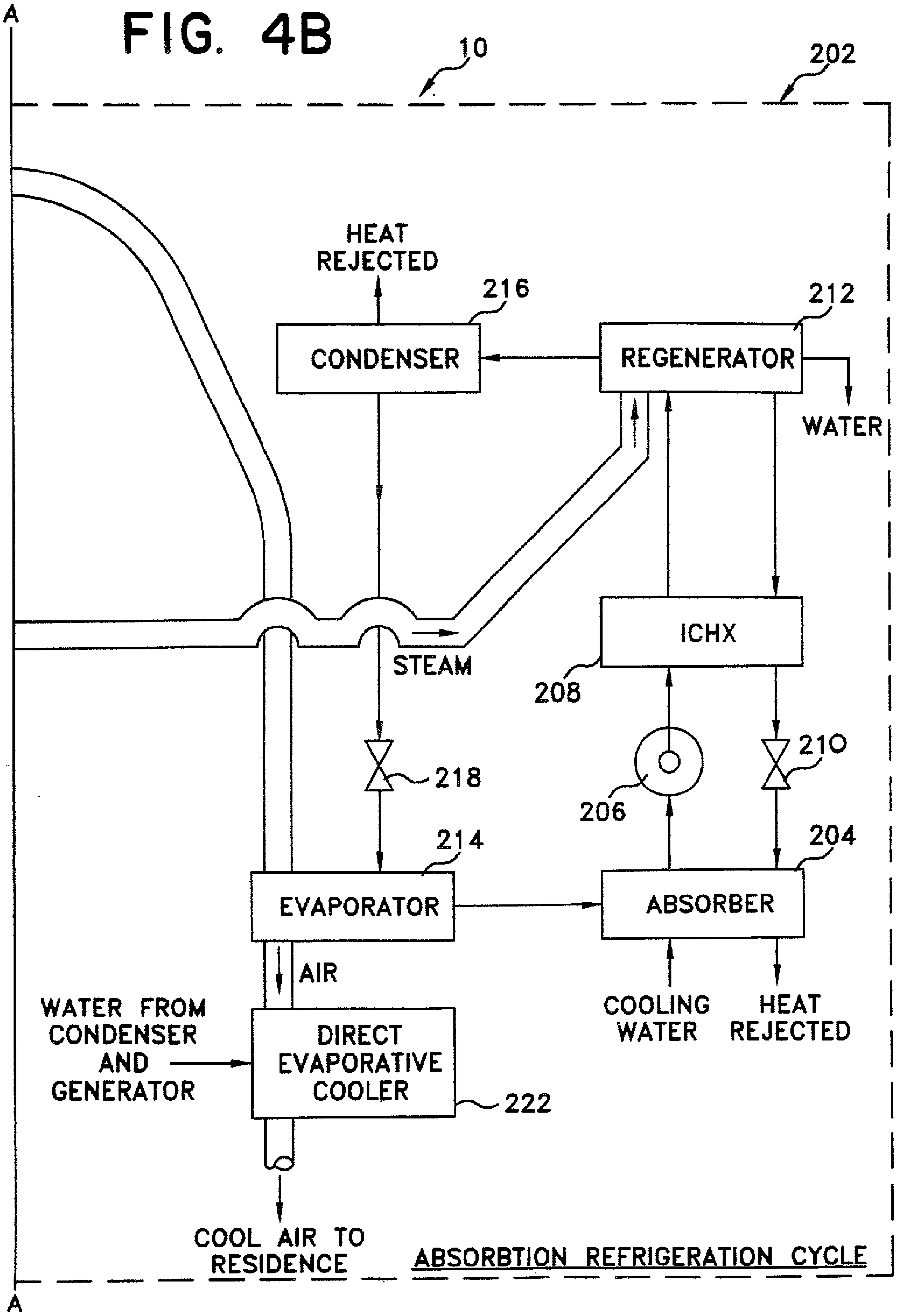

WATER FROM
CONDENSER
AND REGENERATOR
A
200
10
220
INDIRECT
EVAPORATIVE
COOLER
EXHAUST AIR
FROM THE
RESIDENCE
12
ABSORBER
FRESH AIR
80
66
SPLIT ICHX
86
STEAM
CONDENSER
WATER
58
COILED ICHX
BOILER
34
STEAM
EXTERNAL HEAT
LIQUID DEHUMIDIFIER
A

FIG. 4B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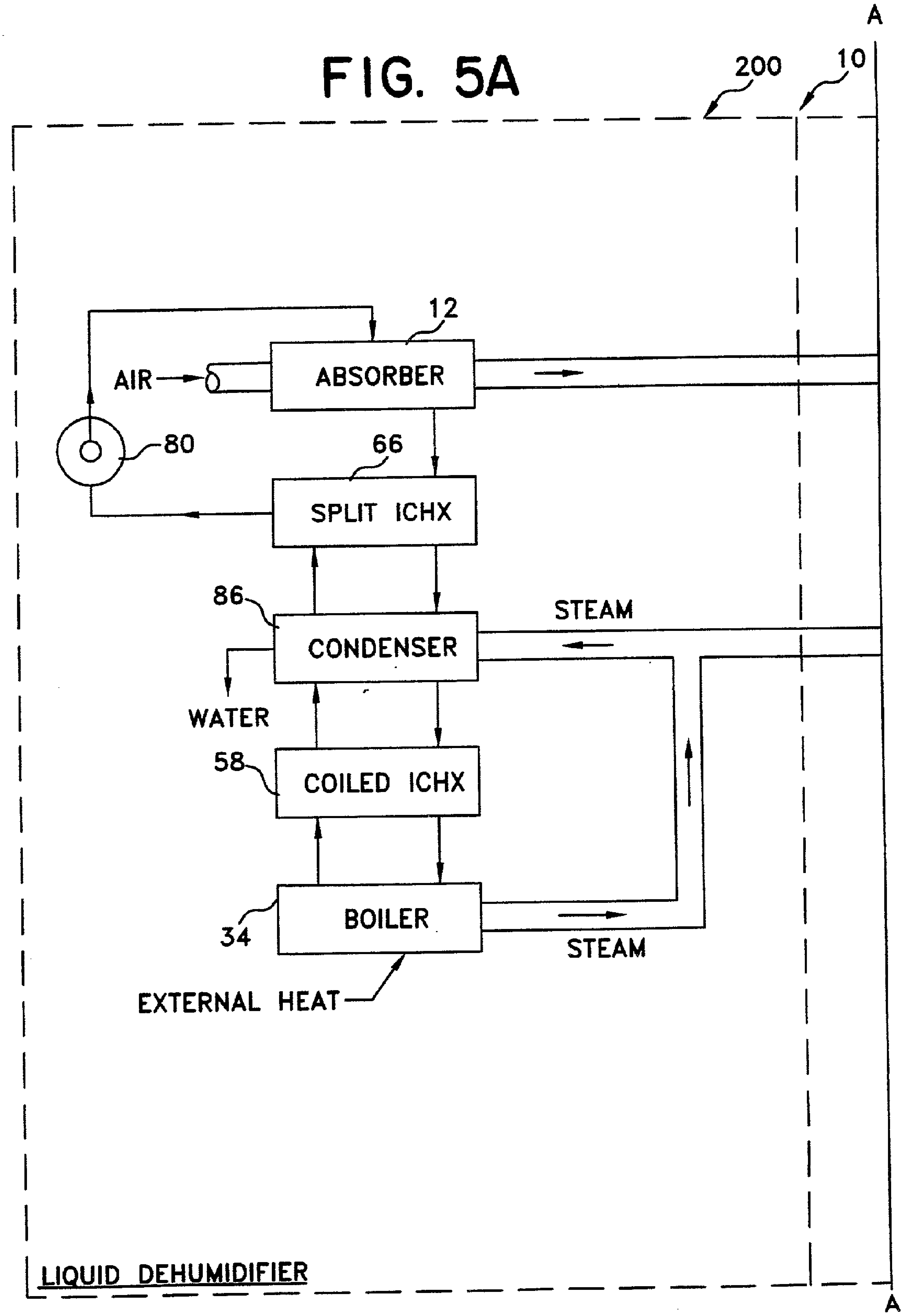
REJECTED
216
212
CONDENSER
REGENERATOR
WATER
ICHX
STEAM
208
218
206
210
214
204
EVAPORATOR
ABSORBER
AIR
WATER FROM
CONDENSER
AND
GENERATOR
DIRECT
EVAPORATIVE
COOLER
222
COOLING
WATER
HEAT
REJECTED
COOL AIR TO
RESIDENCE
ABSORBTION REFRIGERATION CYCLE
A

FIG. 5A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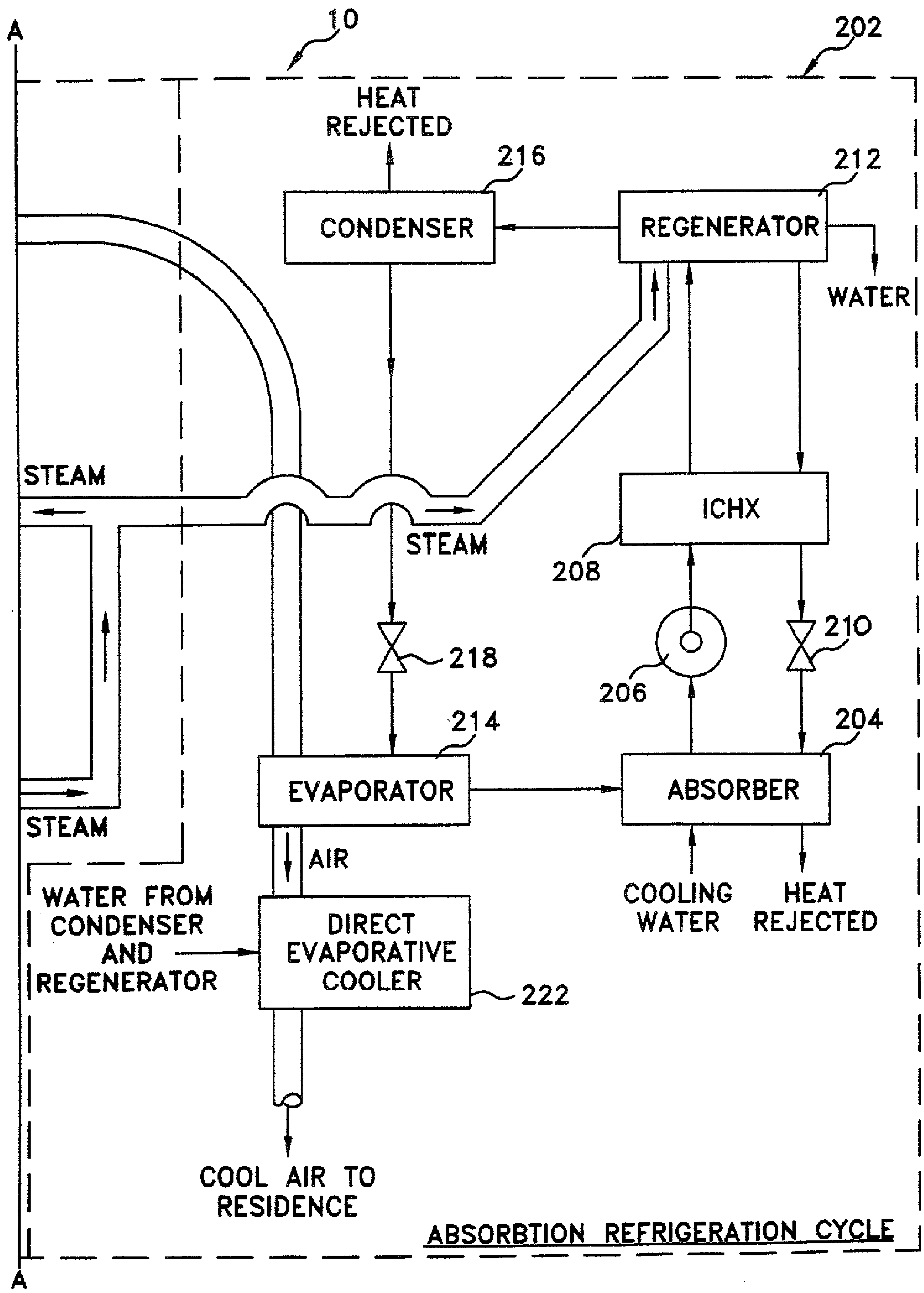
200
10
12
ABSORBER
AIR
80
66
SPLIT ICHX
86
CONDENSER
STEAM
WATER
58
COILED ICHX
BOILER
34
STEAM
EXTERNAL HEAT
LIQUID DEHUMIDIFIER
A

FIG. 5B



A
10
202
HEAT
REJECTED
216
212
CONDENSER
REGENERATOR
WATER
STEAM
ICHX
STEAM
208
218
206
210
214
204
EVAPORATOR
ABSORBER
STEAM
AIR
WATER FROM
CONDENSER
AND
REGENERATOR
DIRECT
EVAPORATIVE
COOLER
222
COOLING
WATER
HEAT
REJECTED
COOL AIR TO
RESIDENCE
ABSORBTION REFRIGERATION CYCLE
A

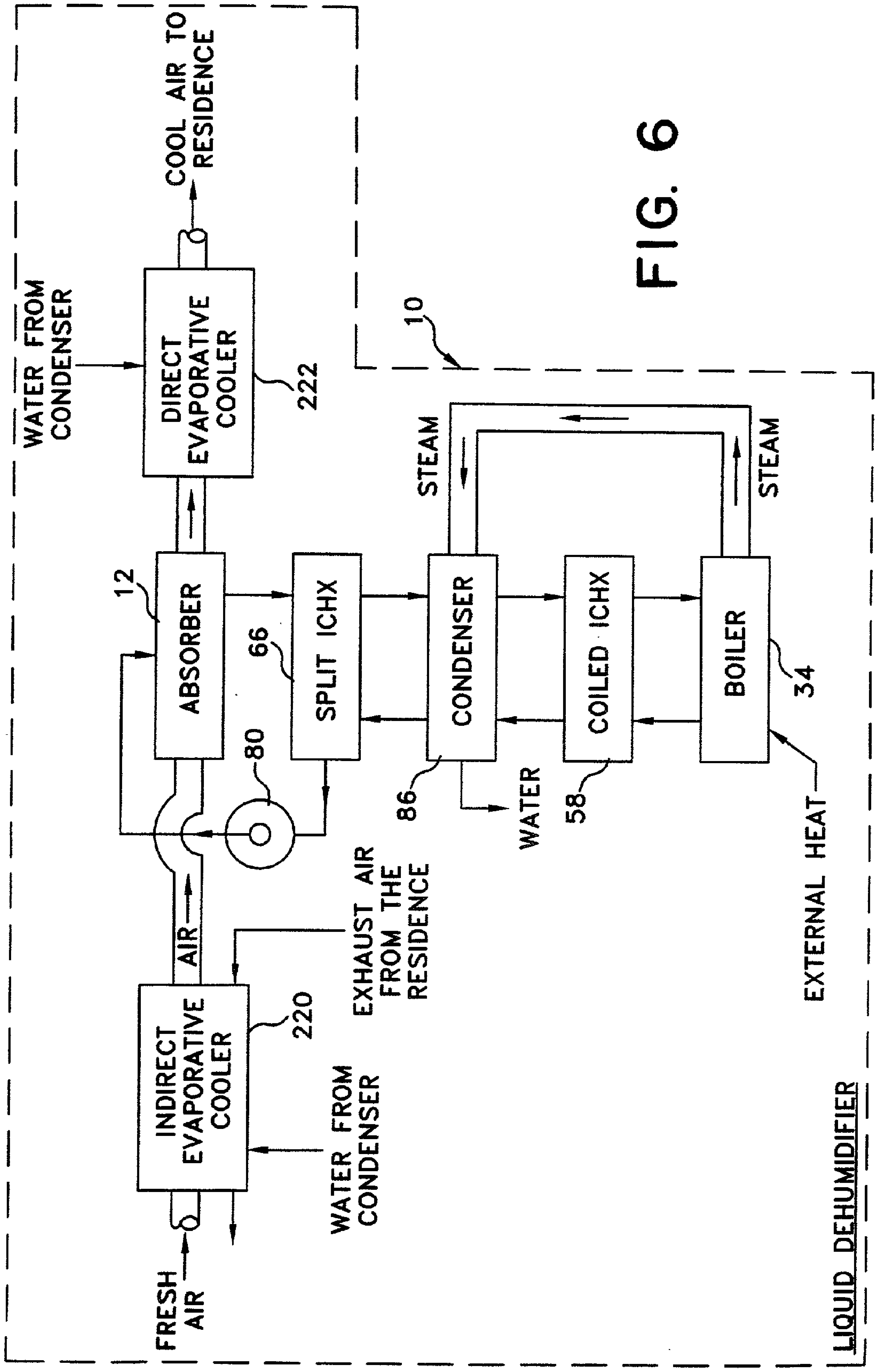

COOL AIR TO RESIDENCE
WATER FROM CONDENSER
DIRECT EVAPORATIVE COOLER
222
10
STEAM
STEAM
12
ABSORBER
SPLIT ICHX
66
CONDENSER
COILED ICHX
BOILER
34
80
86
WATER
58
EXTERNAL HEAT
AIR
EXHAUST AIR FROM THE RESIDENCE
INDIRECT EVAPORATIVE COOLER
220
WATER FROM CONDENSER
FRESH AIR
LIQUID DEHUMIDIFIER

FIG. 6

FIG. 7

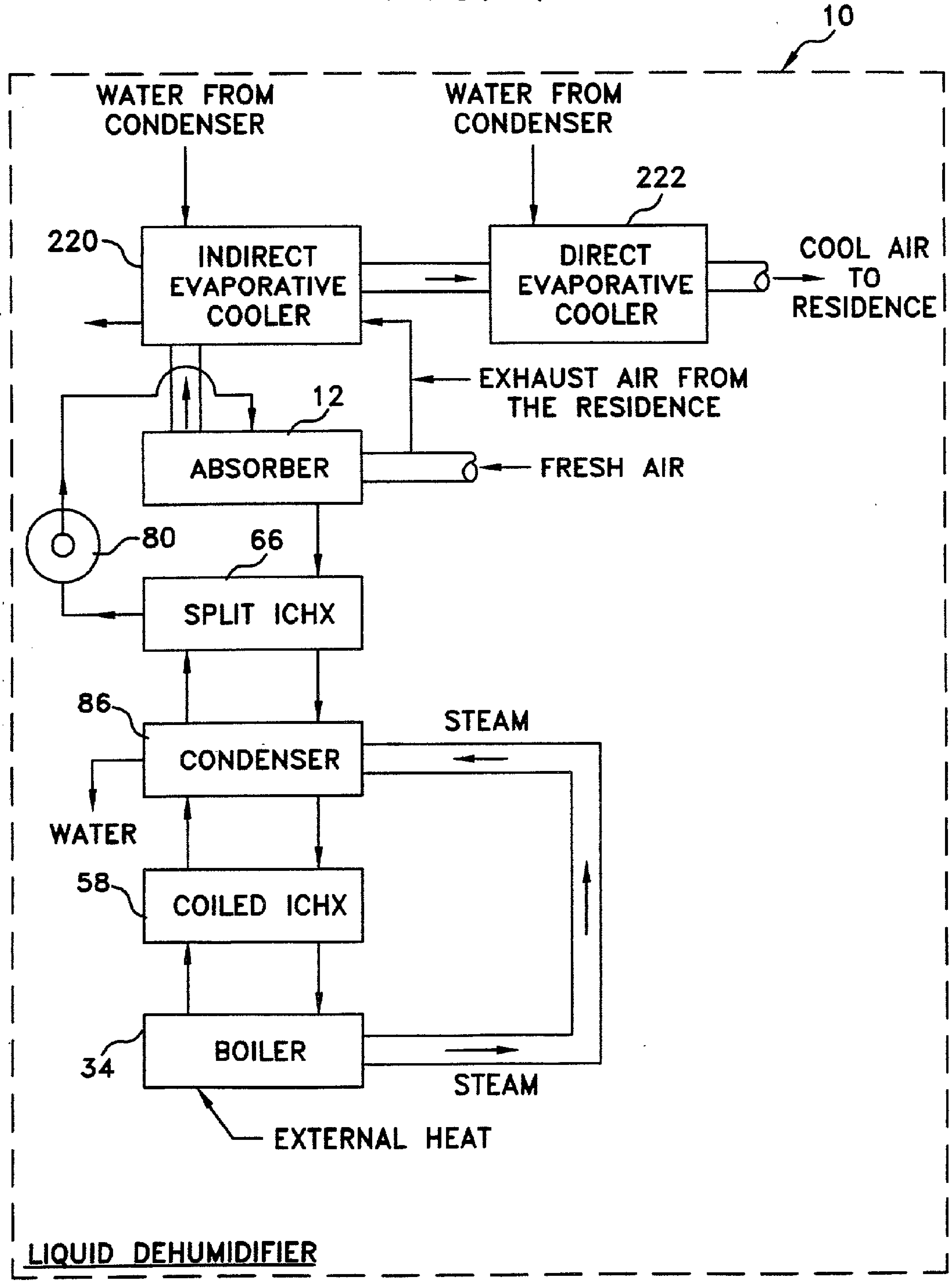
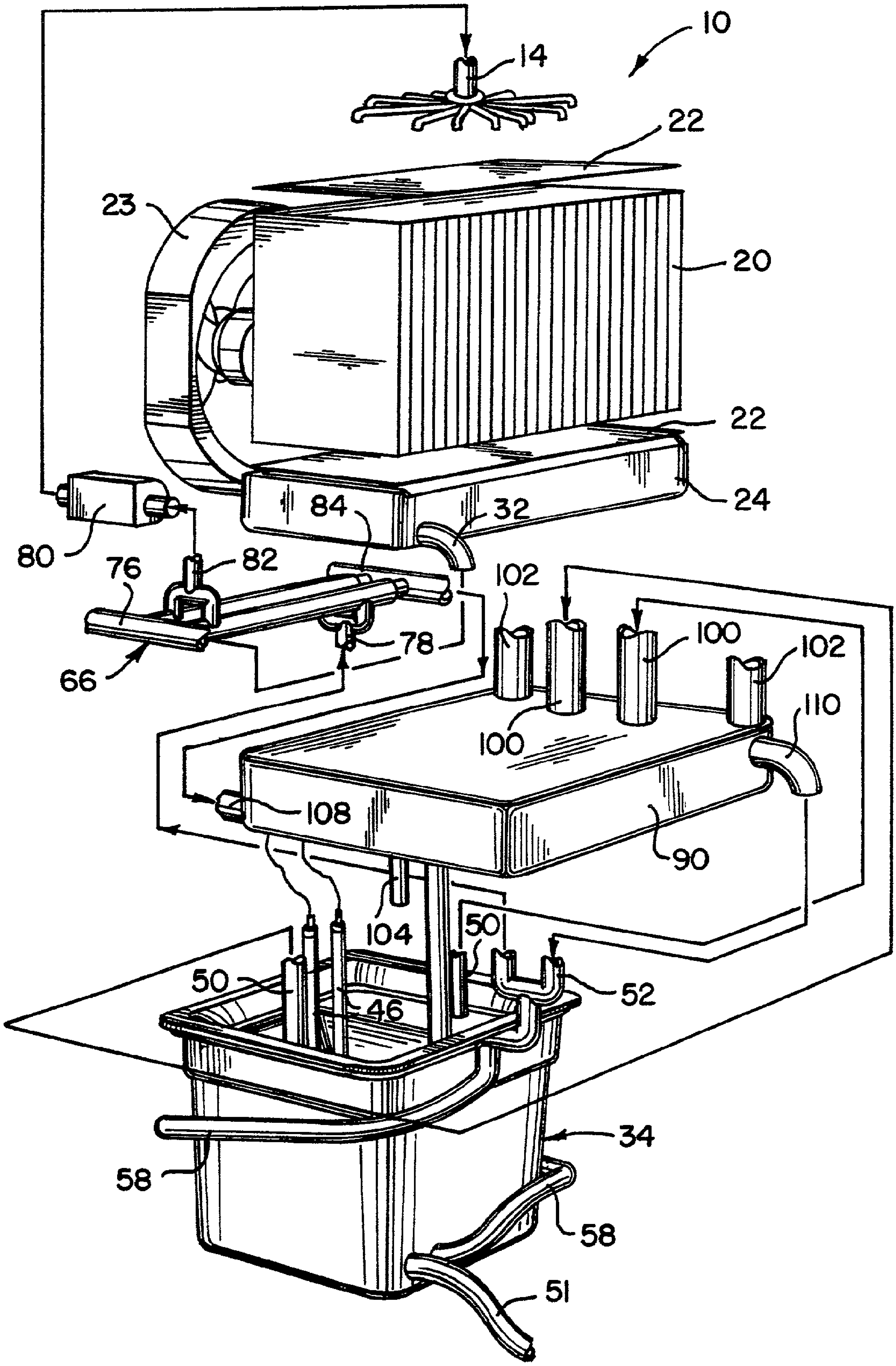

10
WATER FROM CONDENSER
WATER FROM CONDENSER
222
220
INDIRECT EVAPORATIVE COOLER
DIRECT EVAPORATIVE COOLER
COOL AIR TO RESIDENCE
EXHAUST AIR FROM THE RESIDENCE
12
ABSORBER
FRESH AIR
80
66
SPLIT ICHX
86
CONDENSER
STEAM
WATER
58
COILED ICHX
34
BOILER
STEAM
EXTERNAL HEAT
LIQUID DEHUMIDIFIER

FIG. 8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82
76
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100
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66
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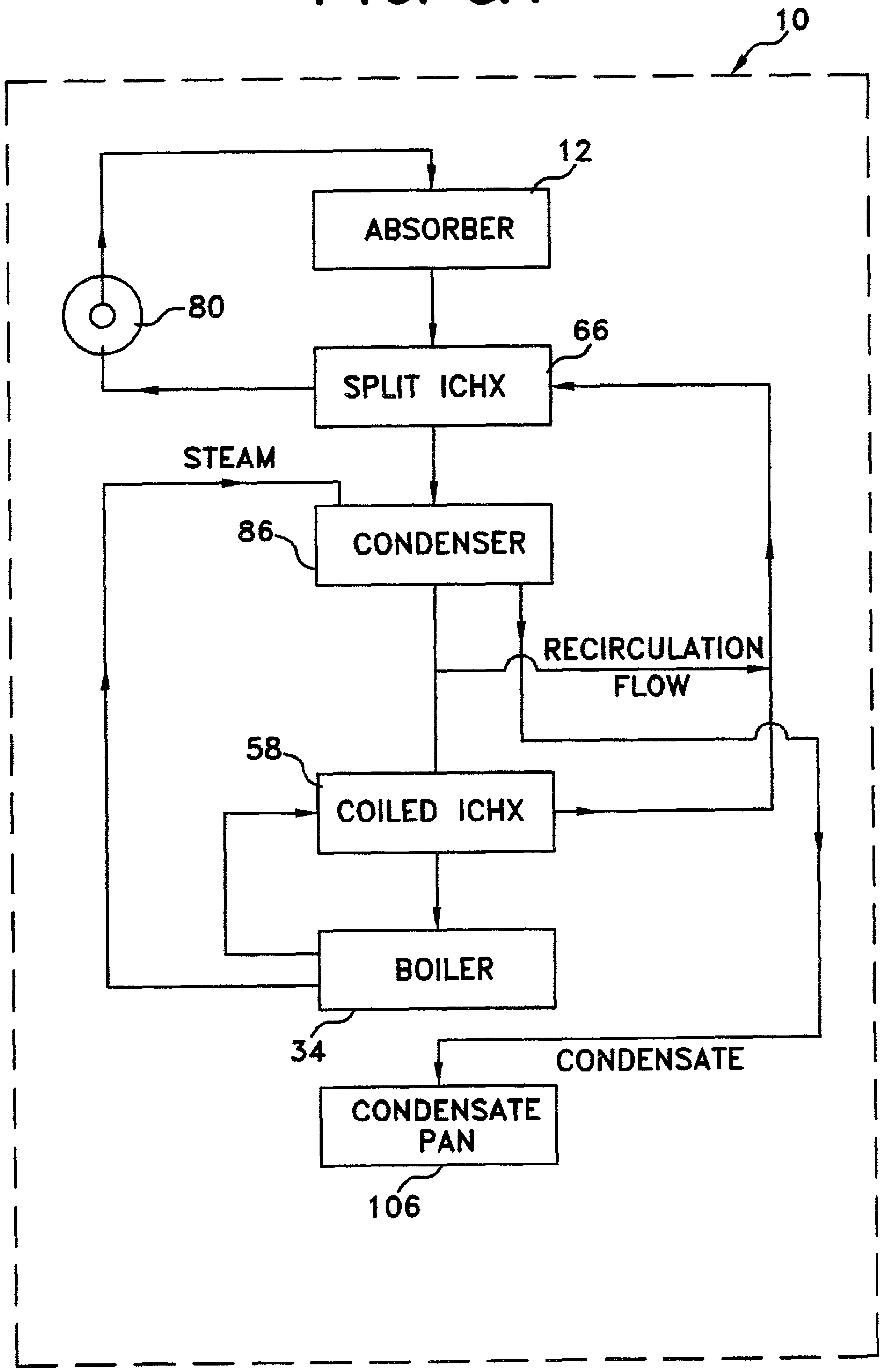
110
108
90
104
50
50
46
52
34
58
58
51

FIG. 8A


10
12
ABSORBER
80
66
SPLIT ICHX
STEAM
86
CONDENSER
RECIRCULATION
FLOW
58
COILED ICHX
BOILER
34
CONDENSATE
CONDENSATE
PAN
106

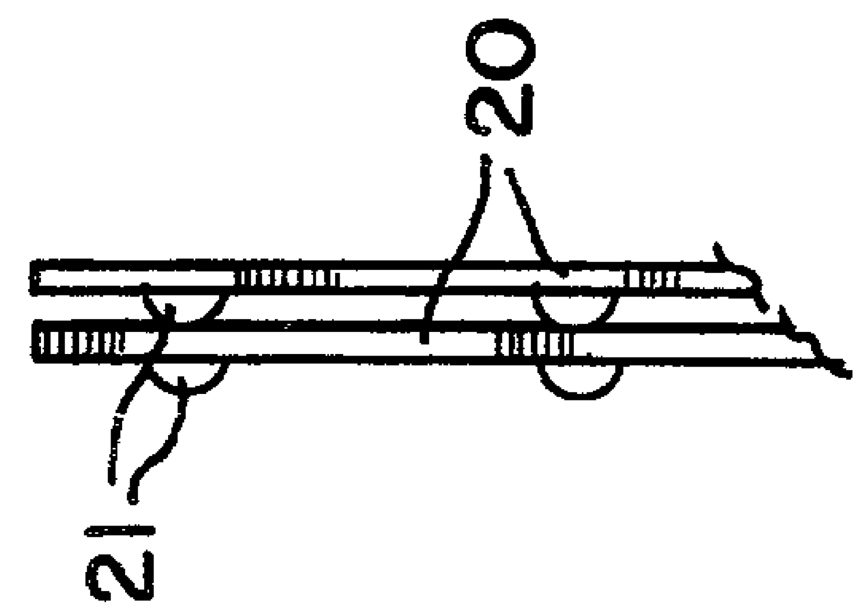


FIG. 9A

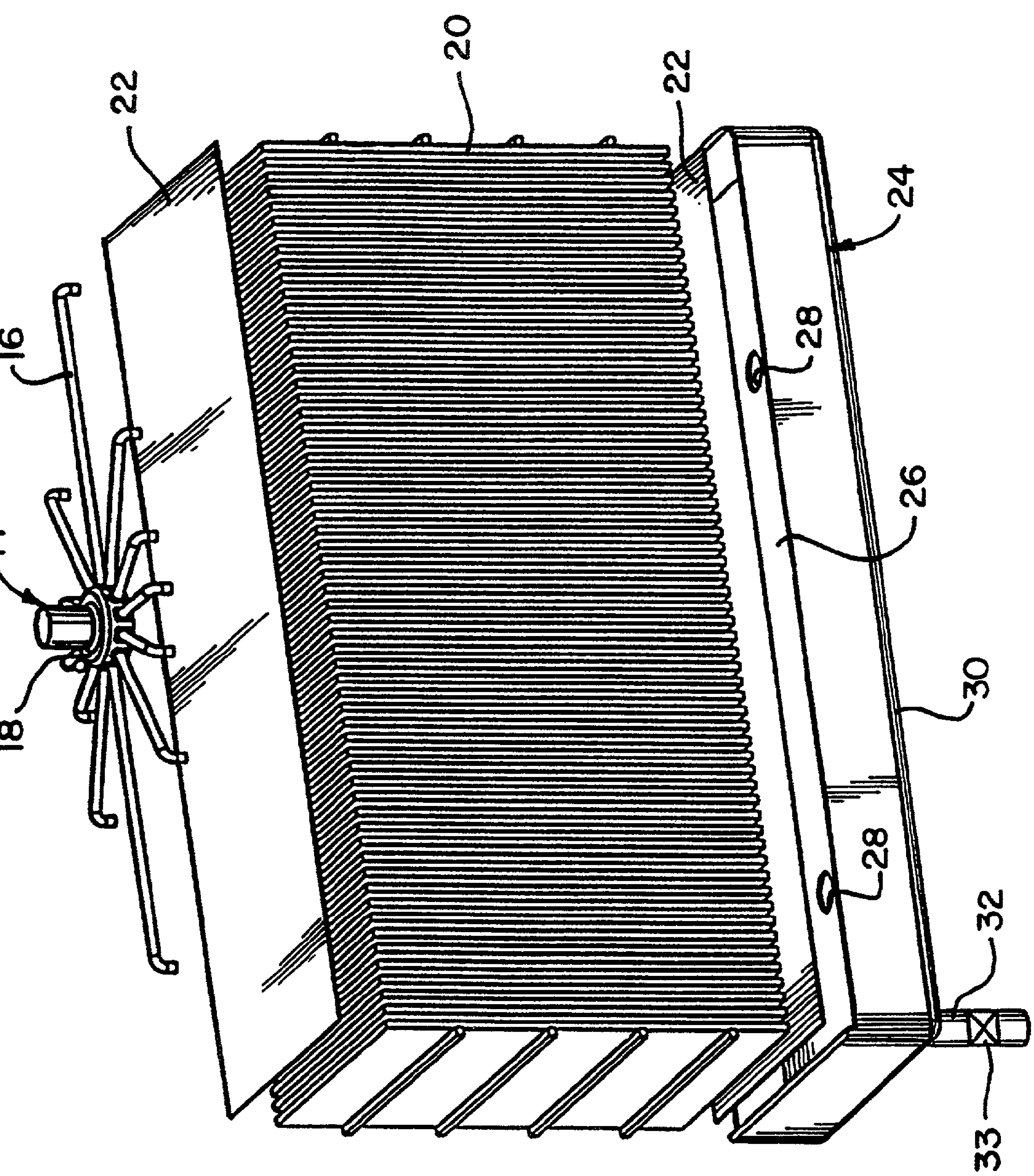


FIG. 9

FIG. 9B

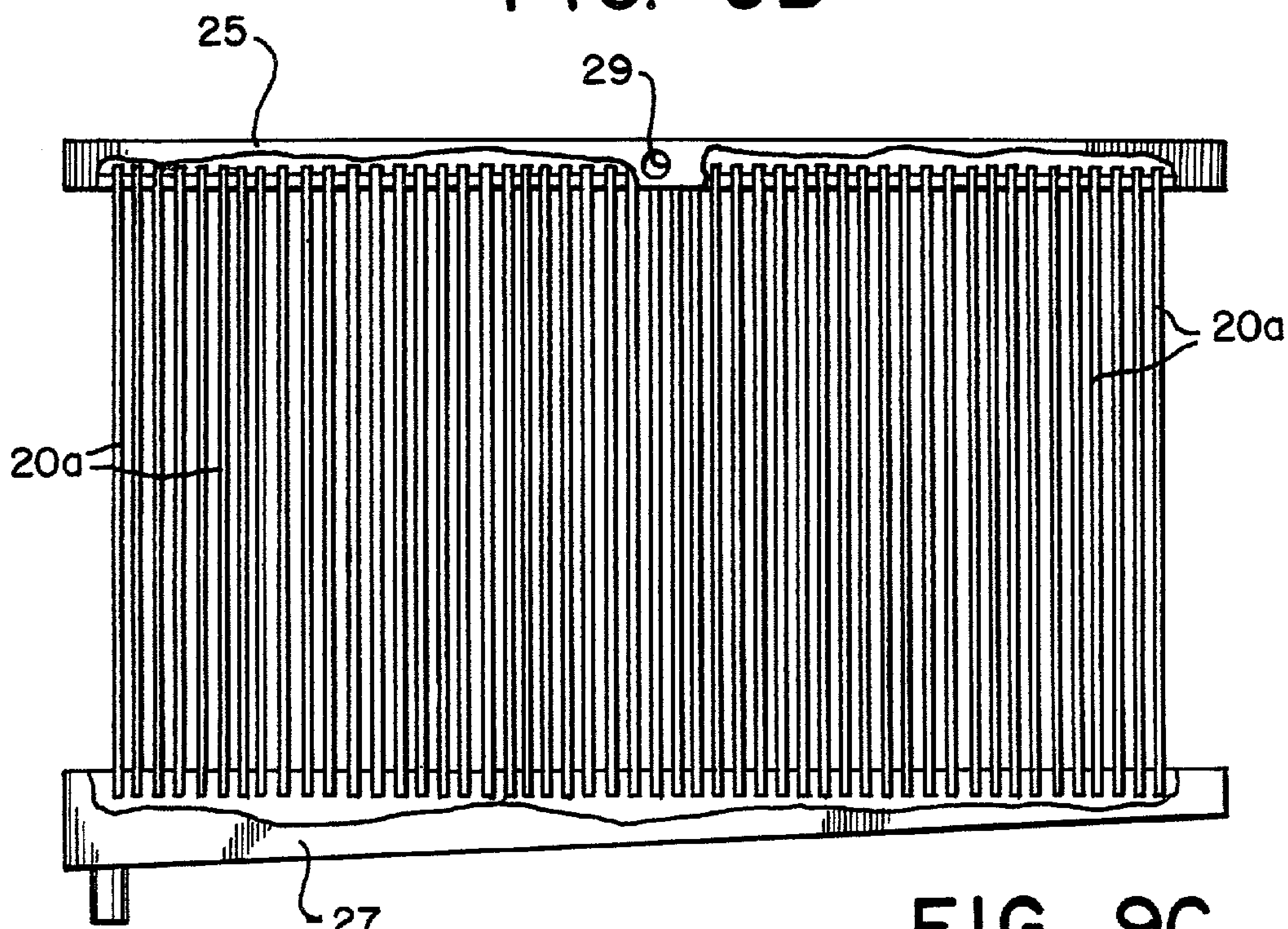
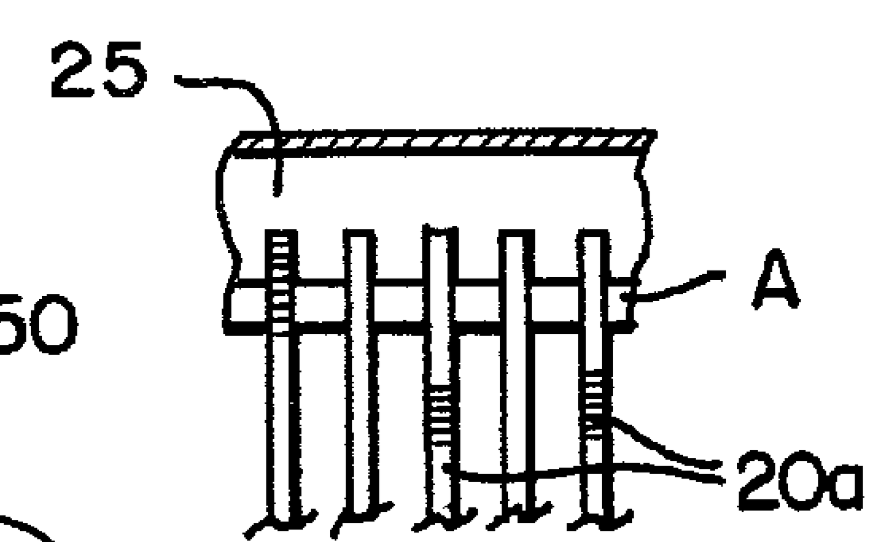


FIG. 9C



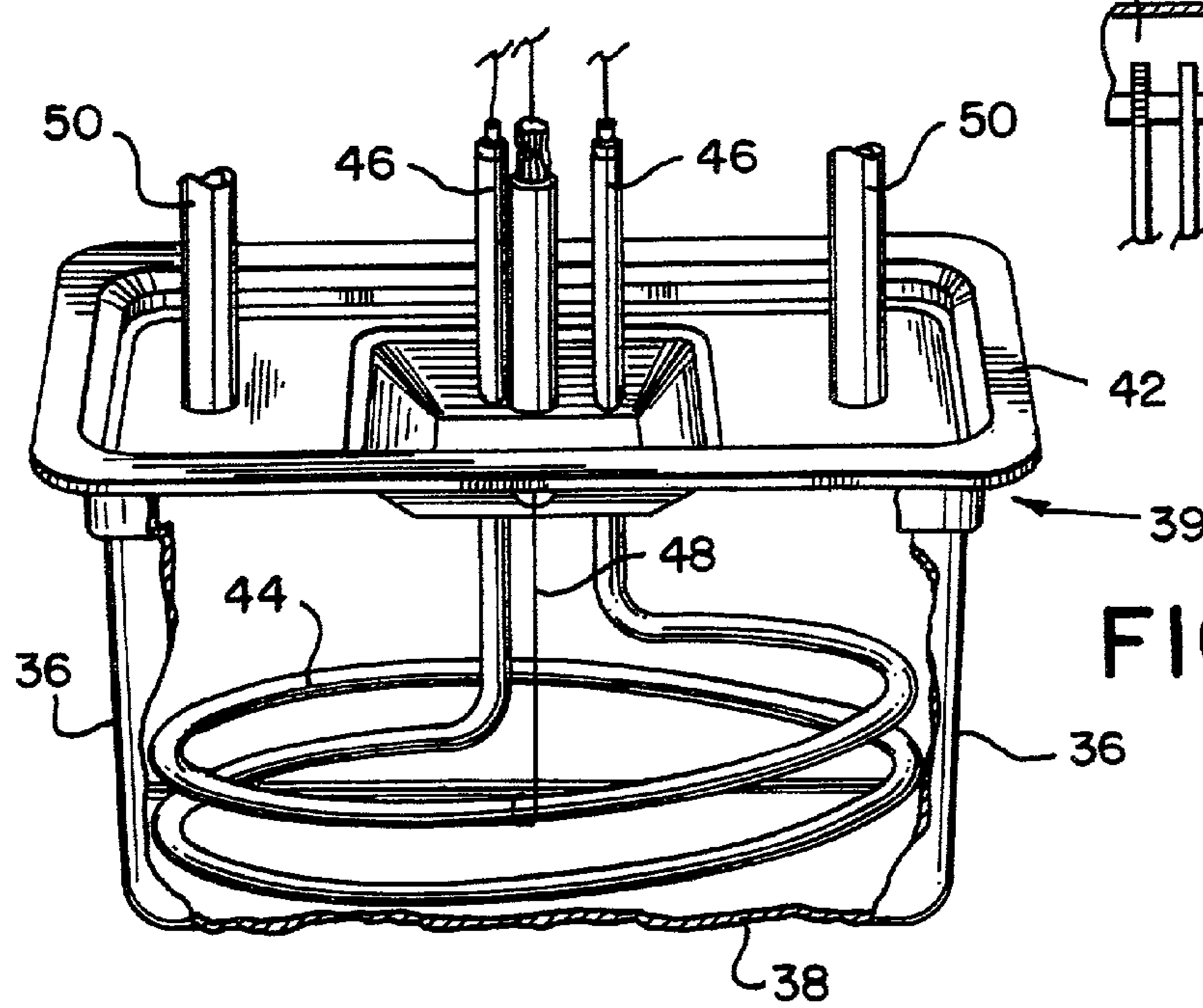


FIG. 10

FIG. 9D

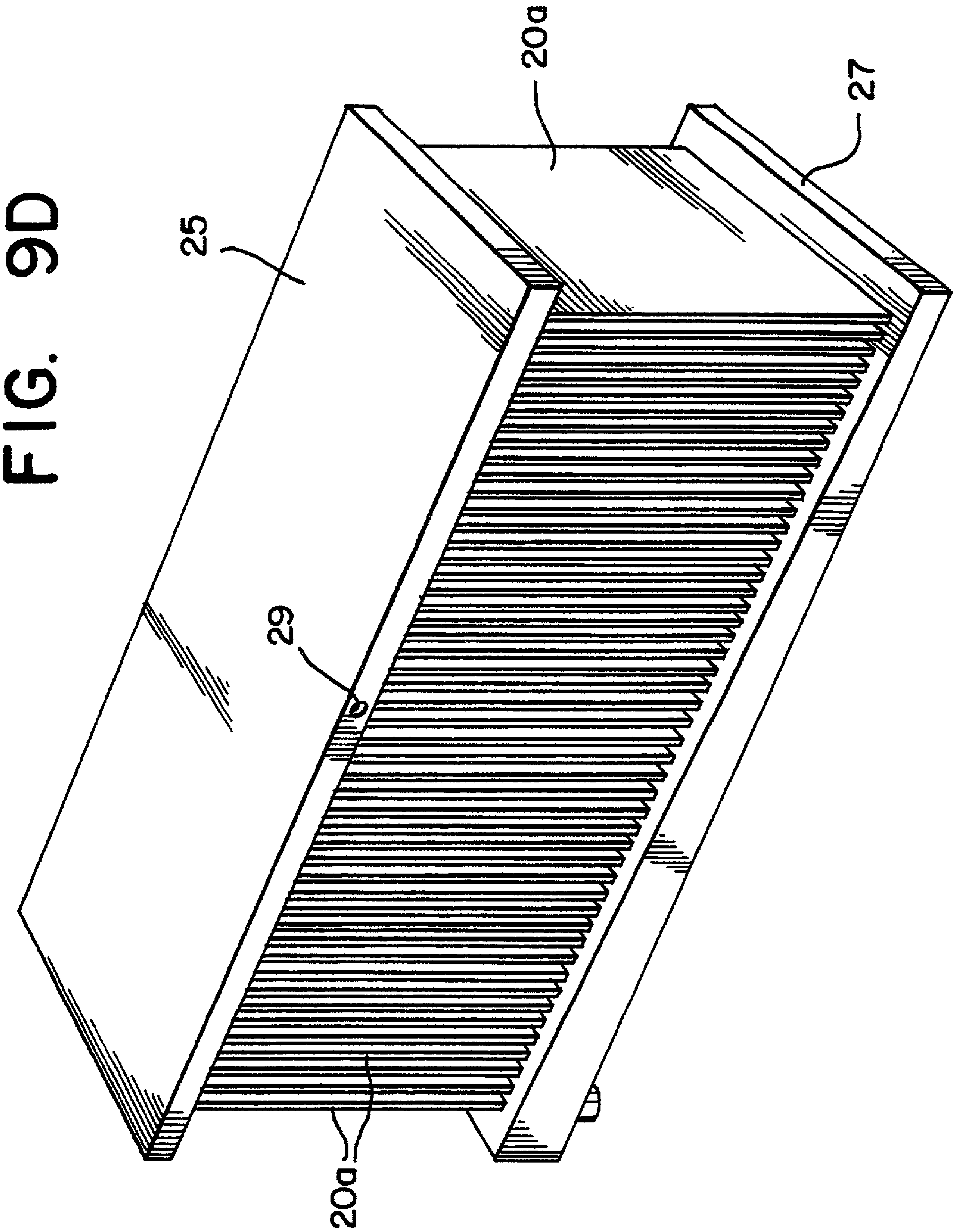


FIG. 11

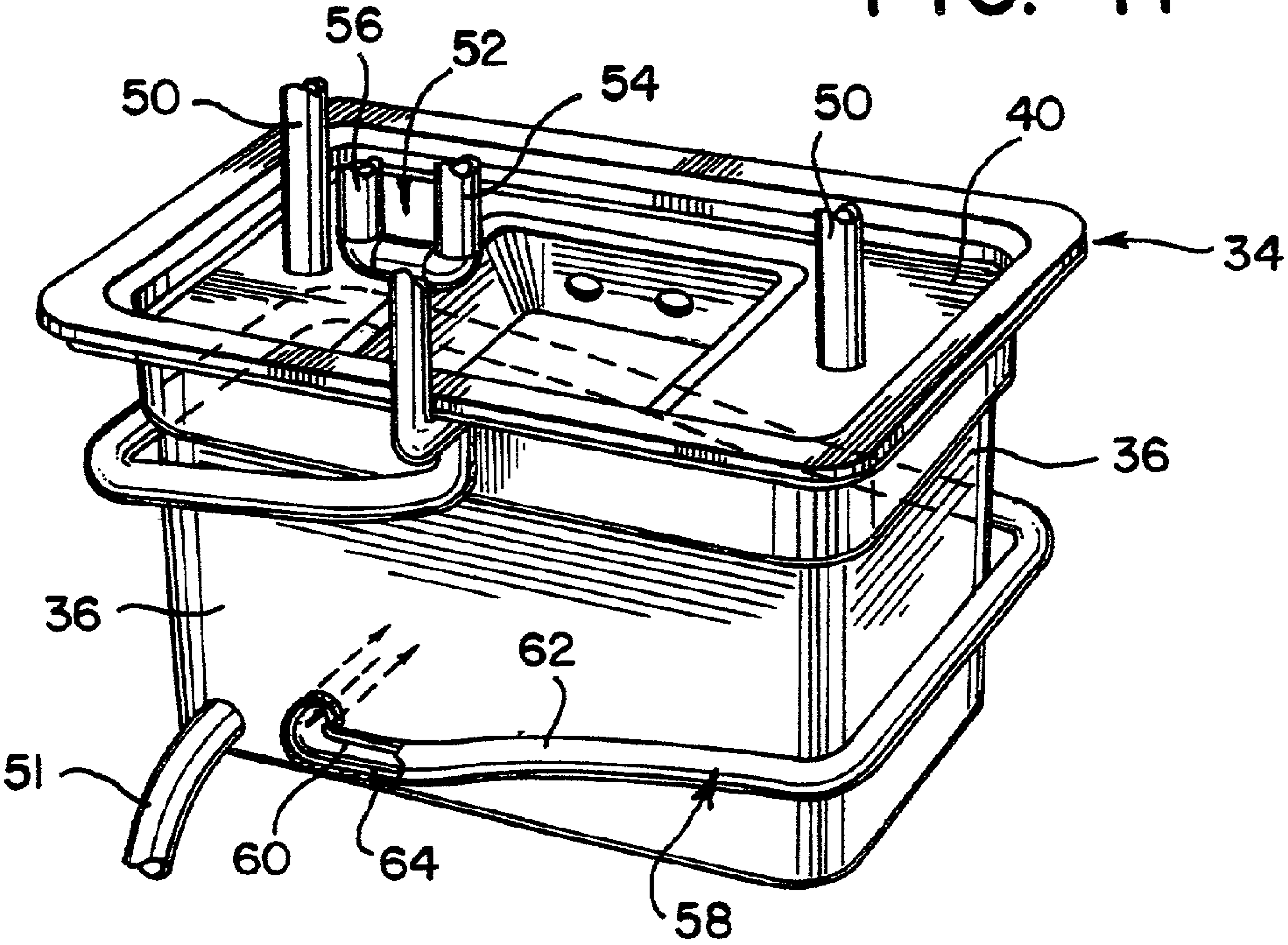


FIG. 11A

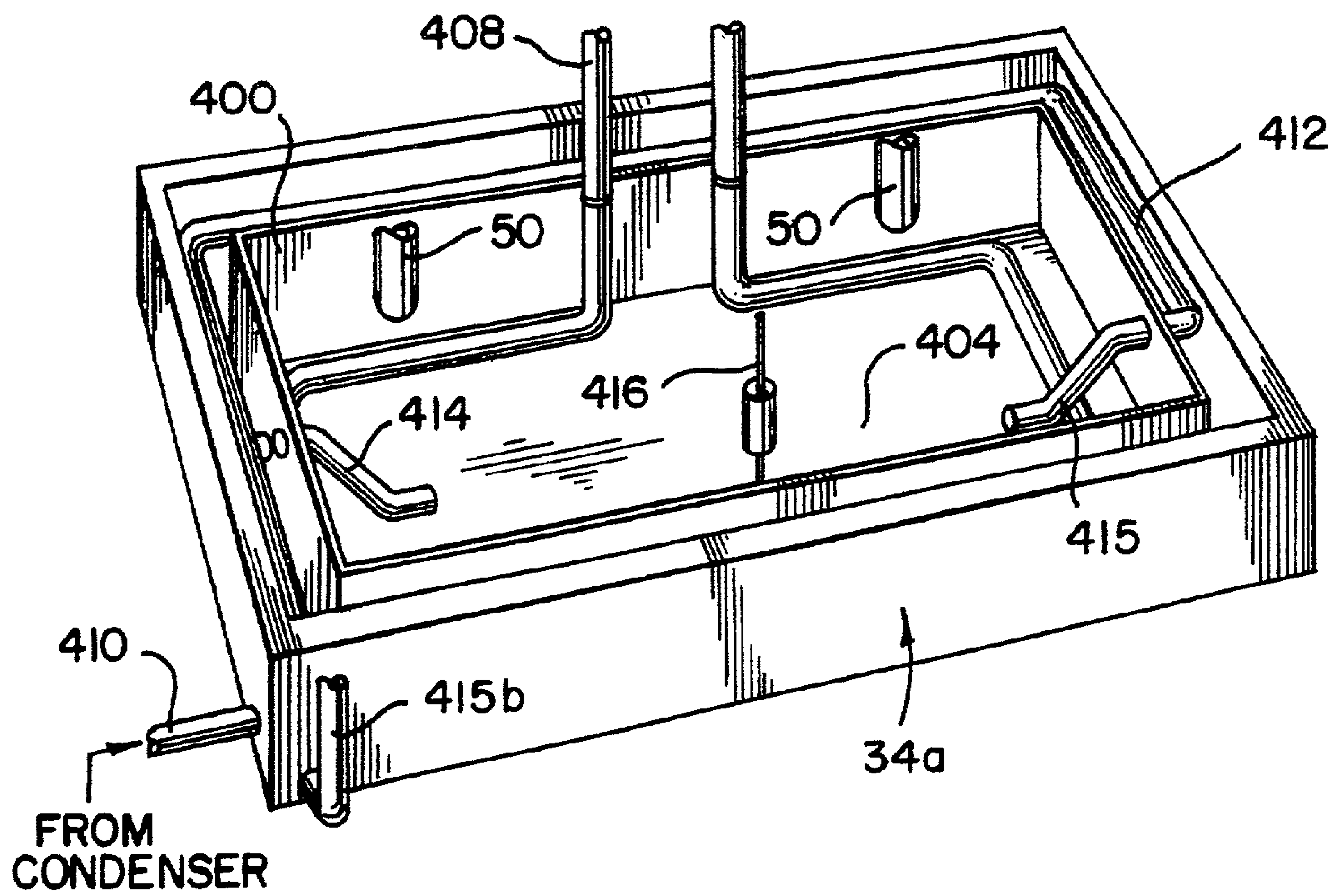


FIG. 12

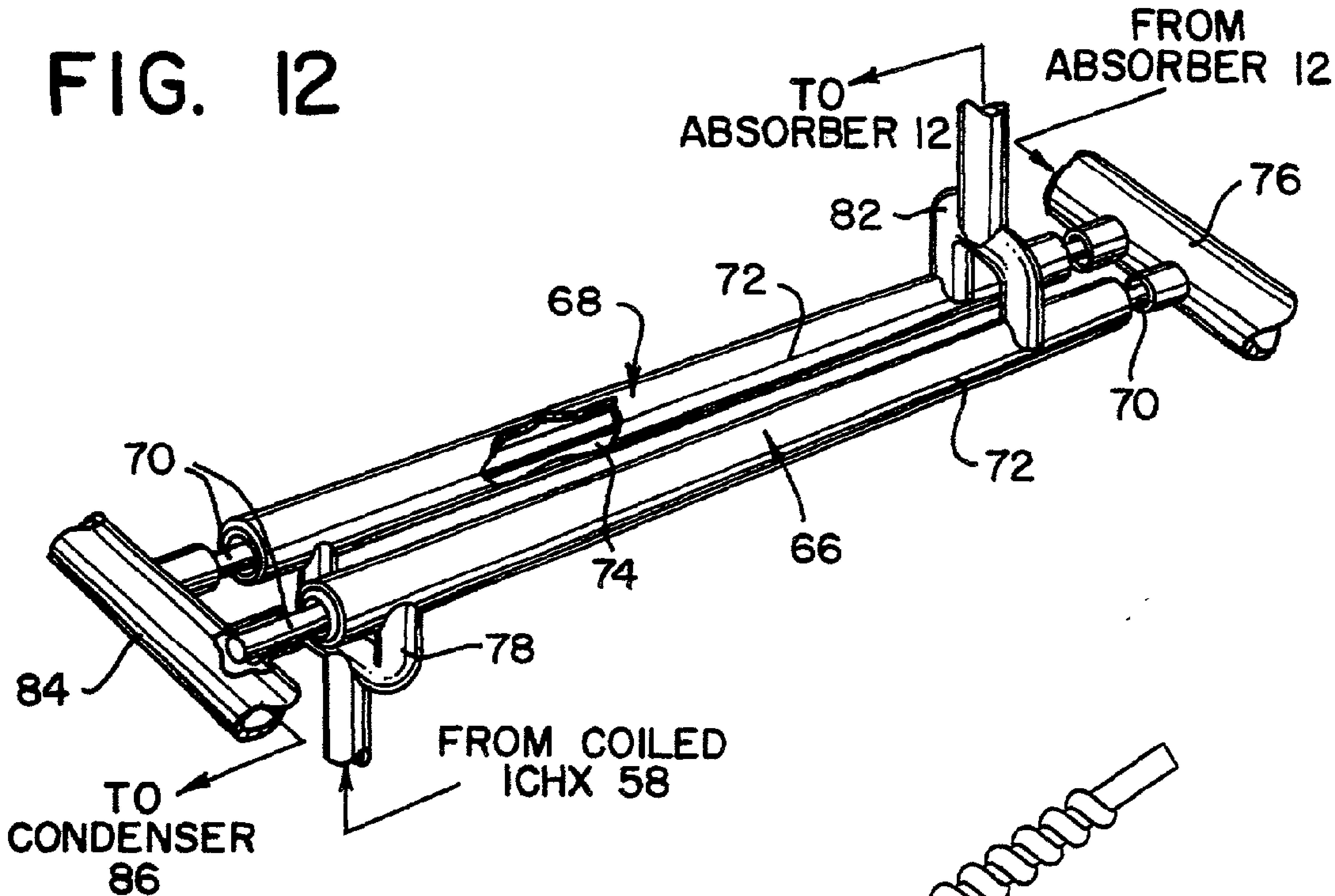


FIG. 12A

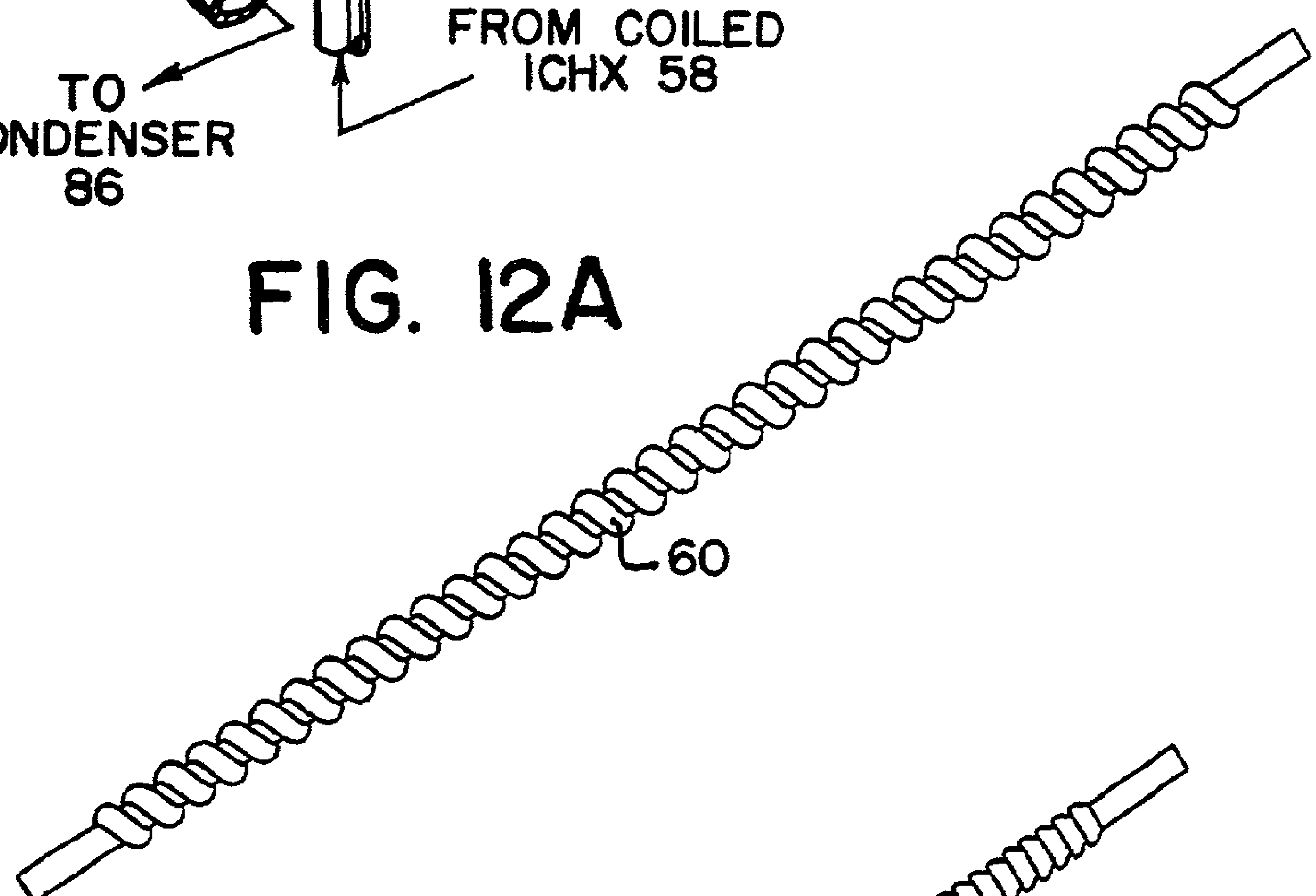


FIG. 12B

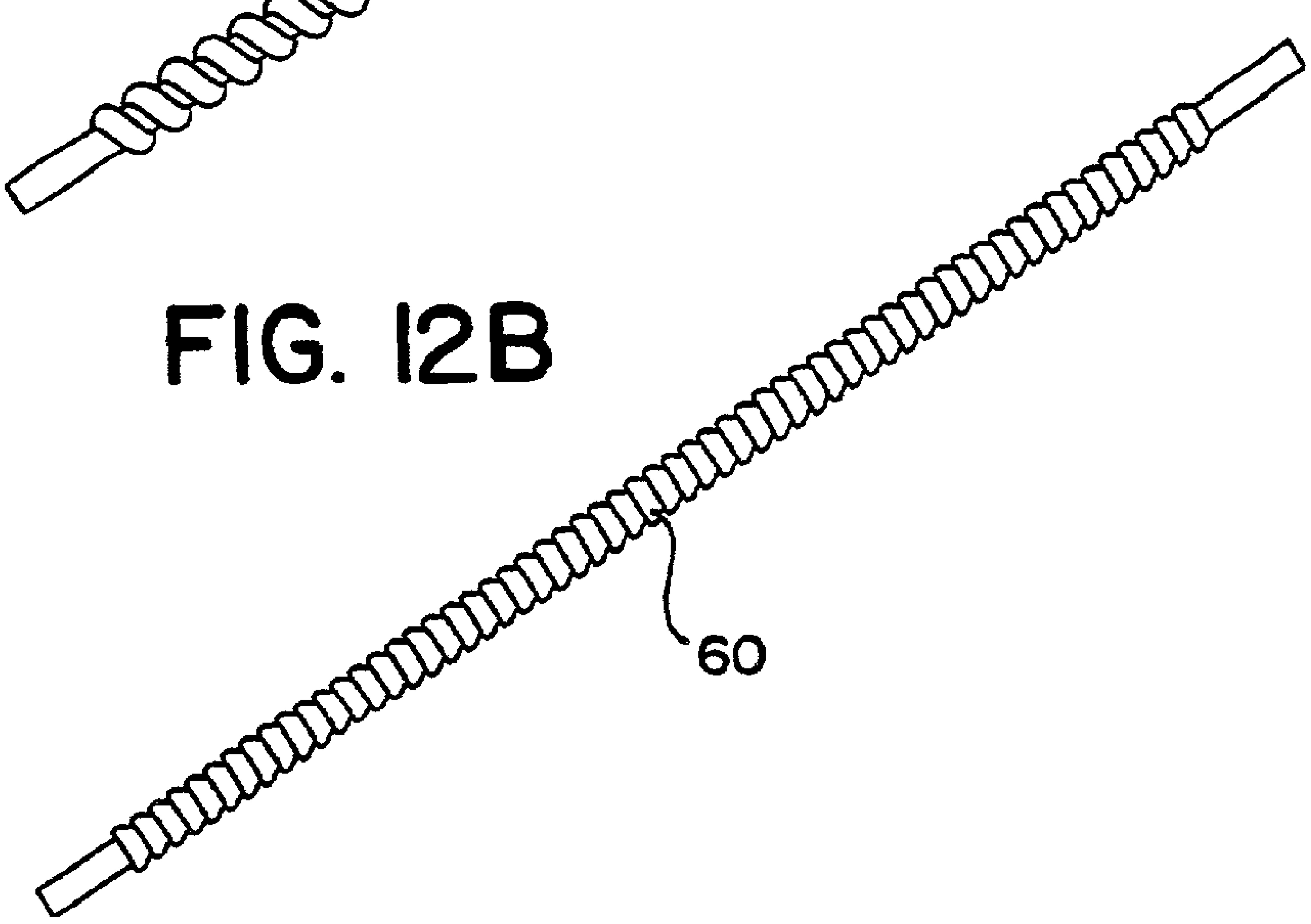


FIG. 13

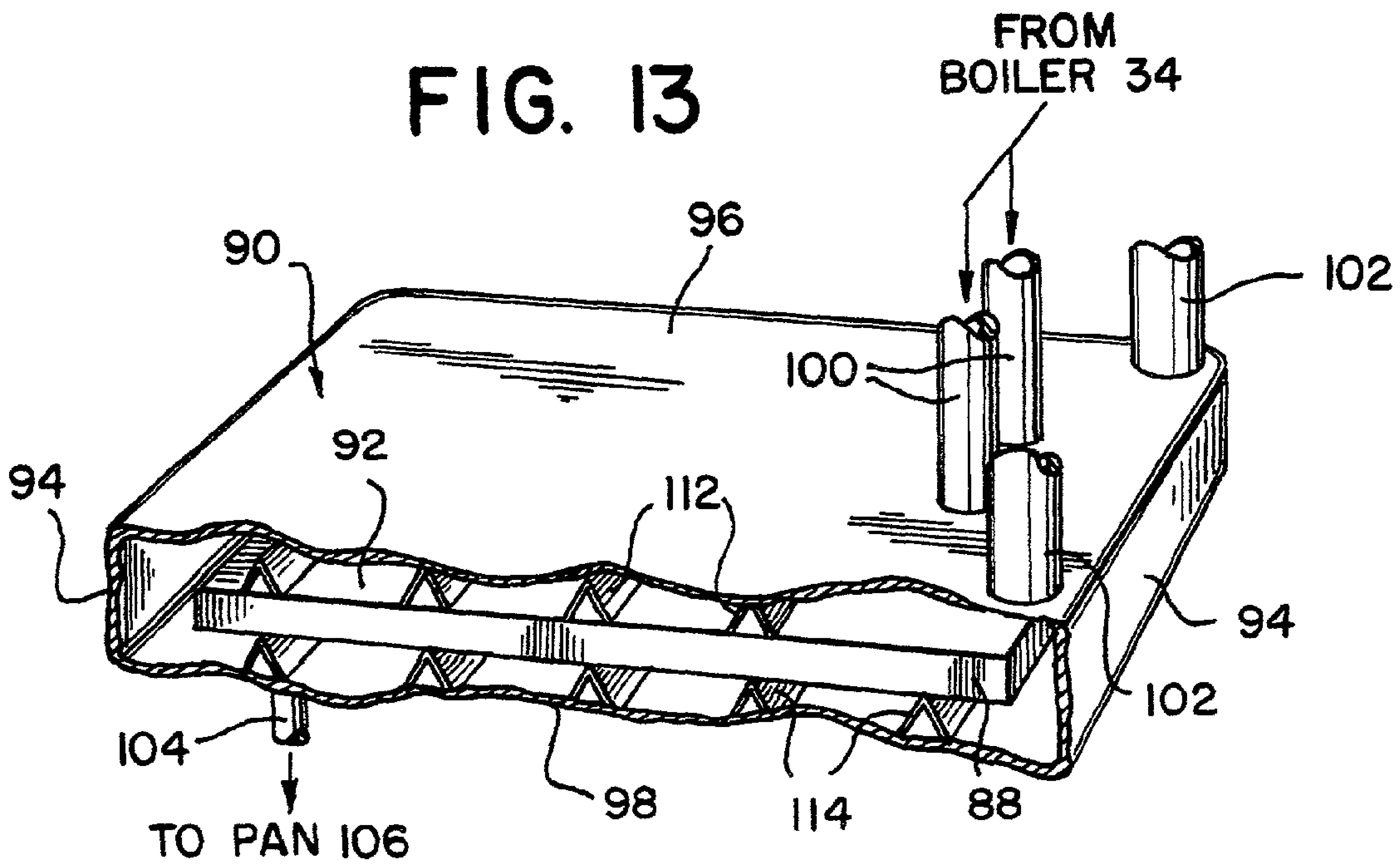

FROM
BOILER 34
90
96
102
100
92
94
112
94
102
104
98
114
88
TO PAN 106

FIG. 14

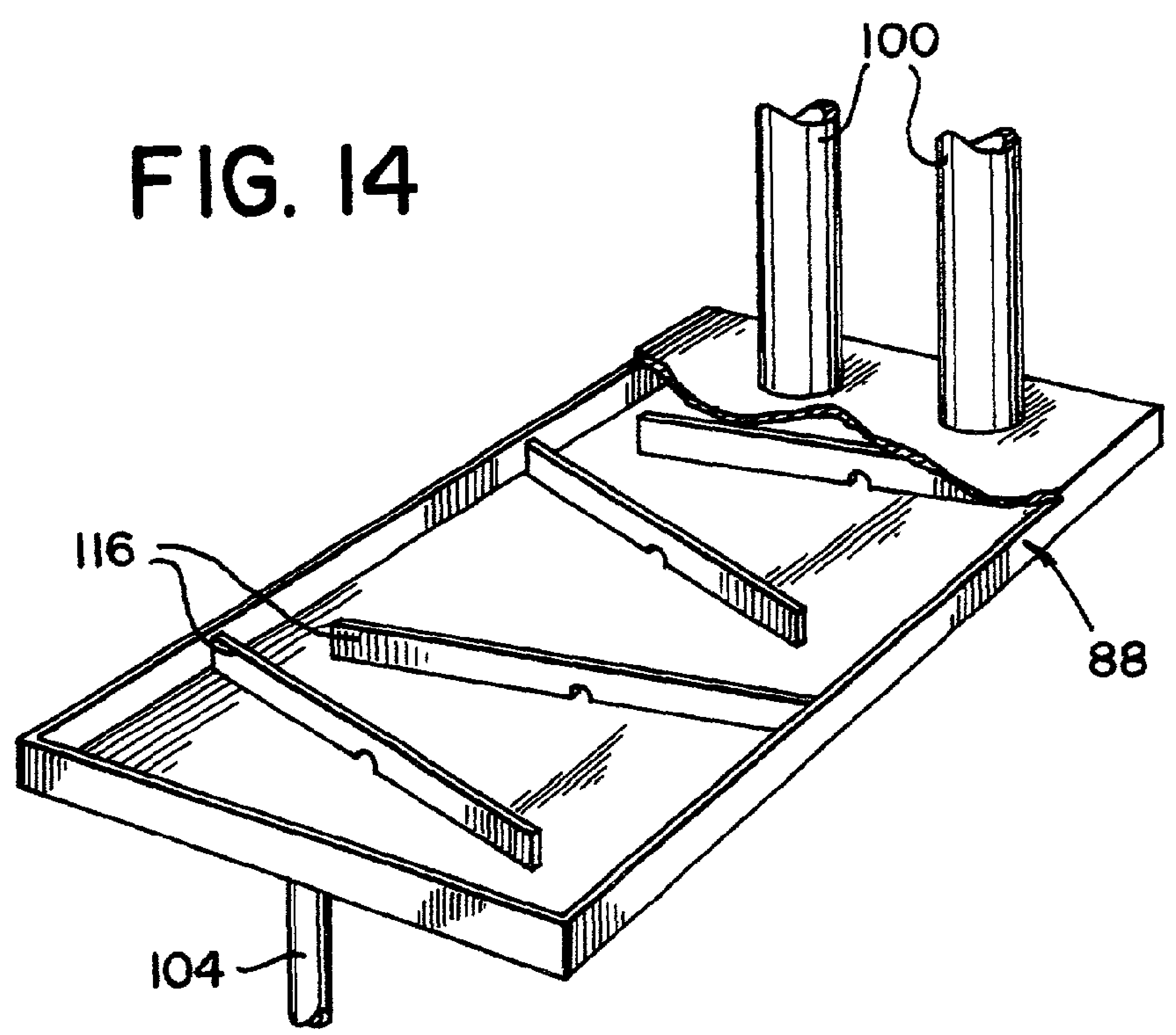

100
116
88
104

FIG. 15

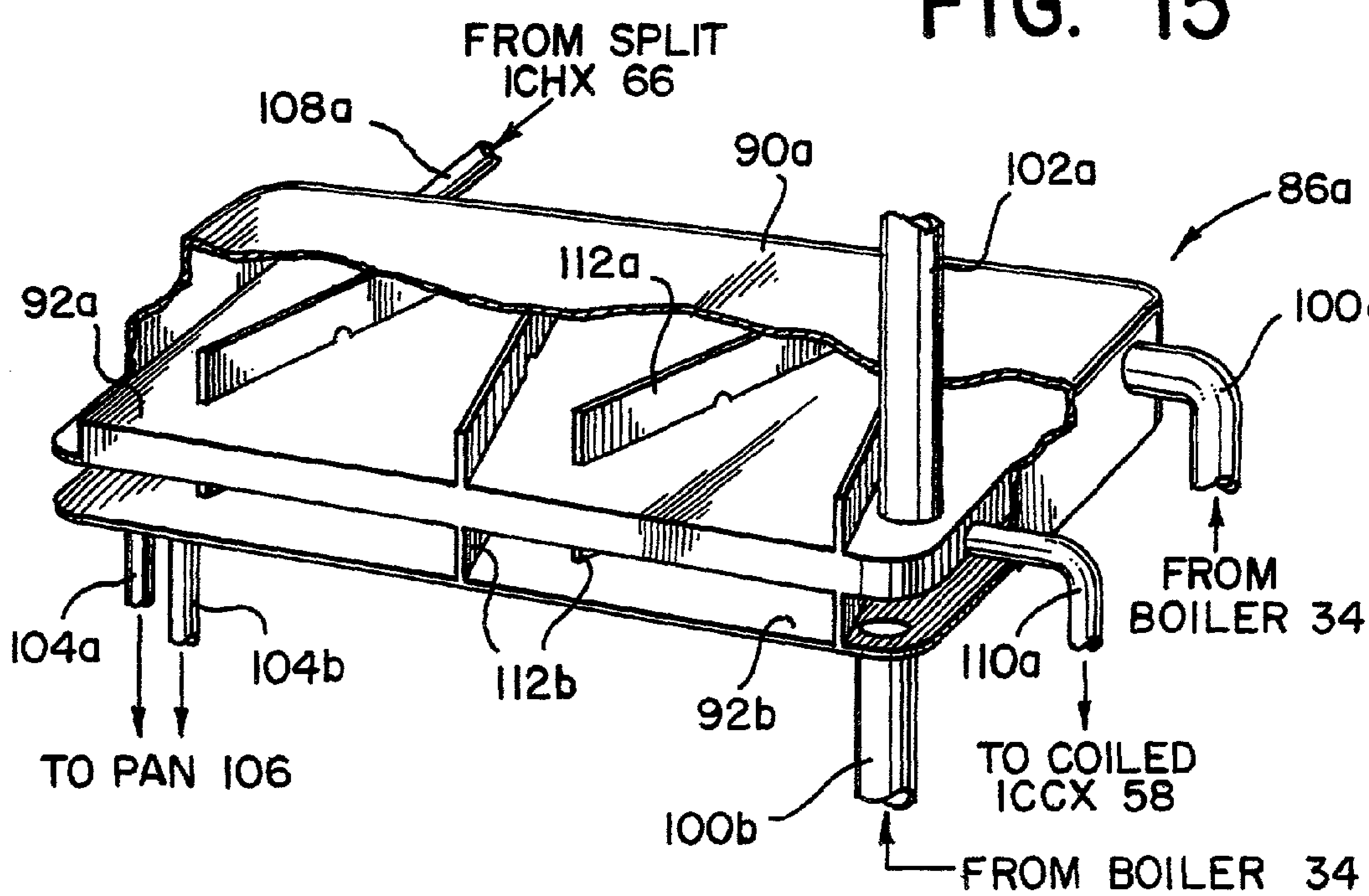
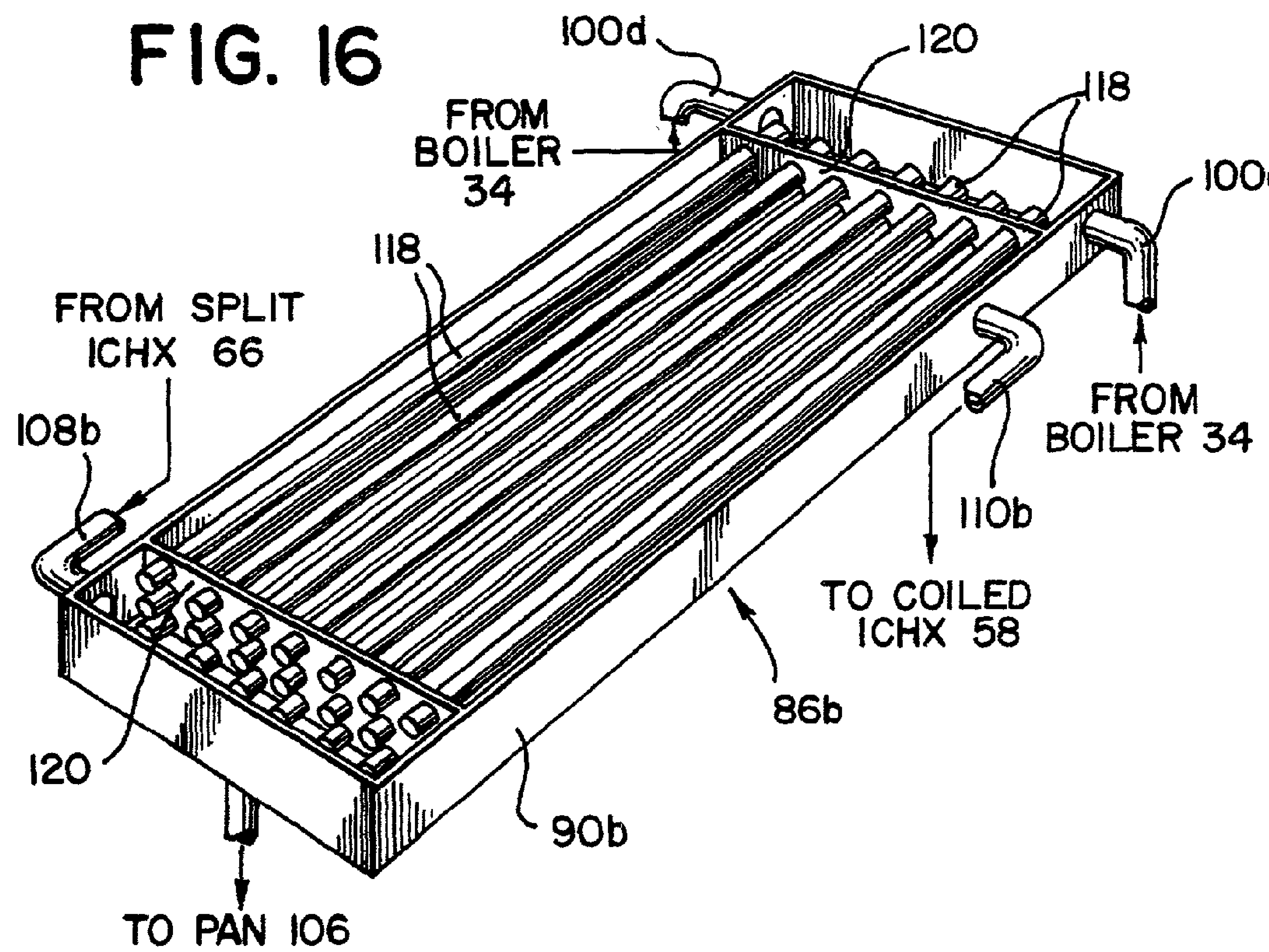

FROM SPLIT
ICHX 66
108a
90a
102a
86a
92a
112a
100a
FROM
BOILER 34
104a
104b
112b
92b
110a
TO PAN 106
TO COILED
ICCX 58
100b
FROM BOILER 34

FIG. 16


100d
120
118
FROM
BOILER
34
100c
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FROM SPLIT
ICHX 66
FROM
BOILER 34
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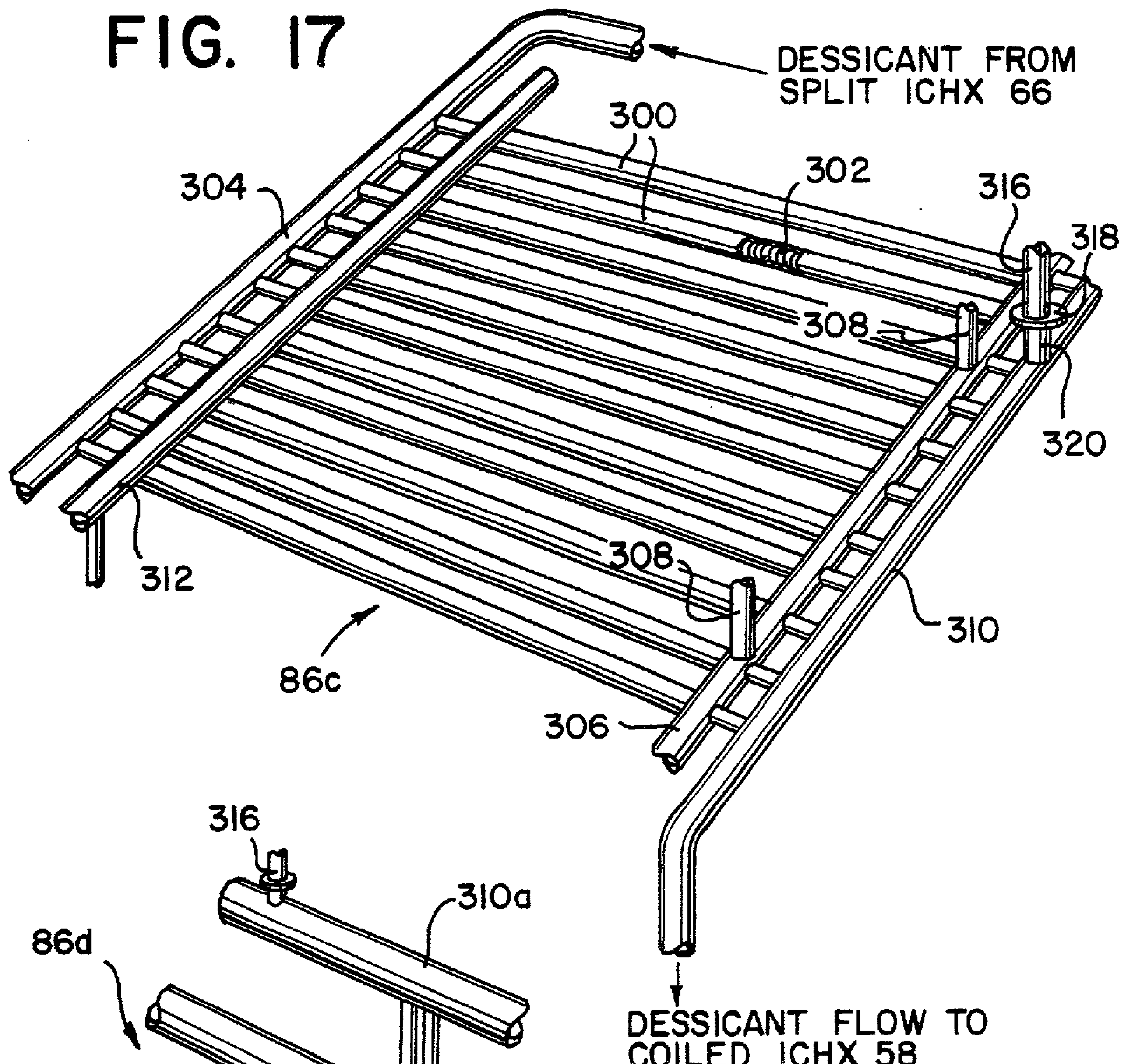
TO COILED
ICHX 58
86b
120
90b
TO PAN 106

FIG. 17


DESSICANT FROM
SPLIT ICHX 66
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304
316
318
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320
312
308
310
86c
306
DESSICANT FLOW TO
COILED ICHX 58

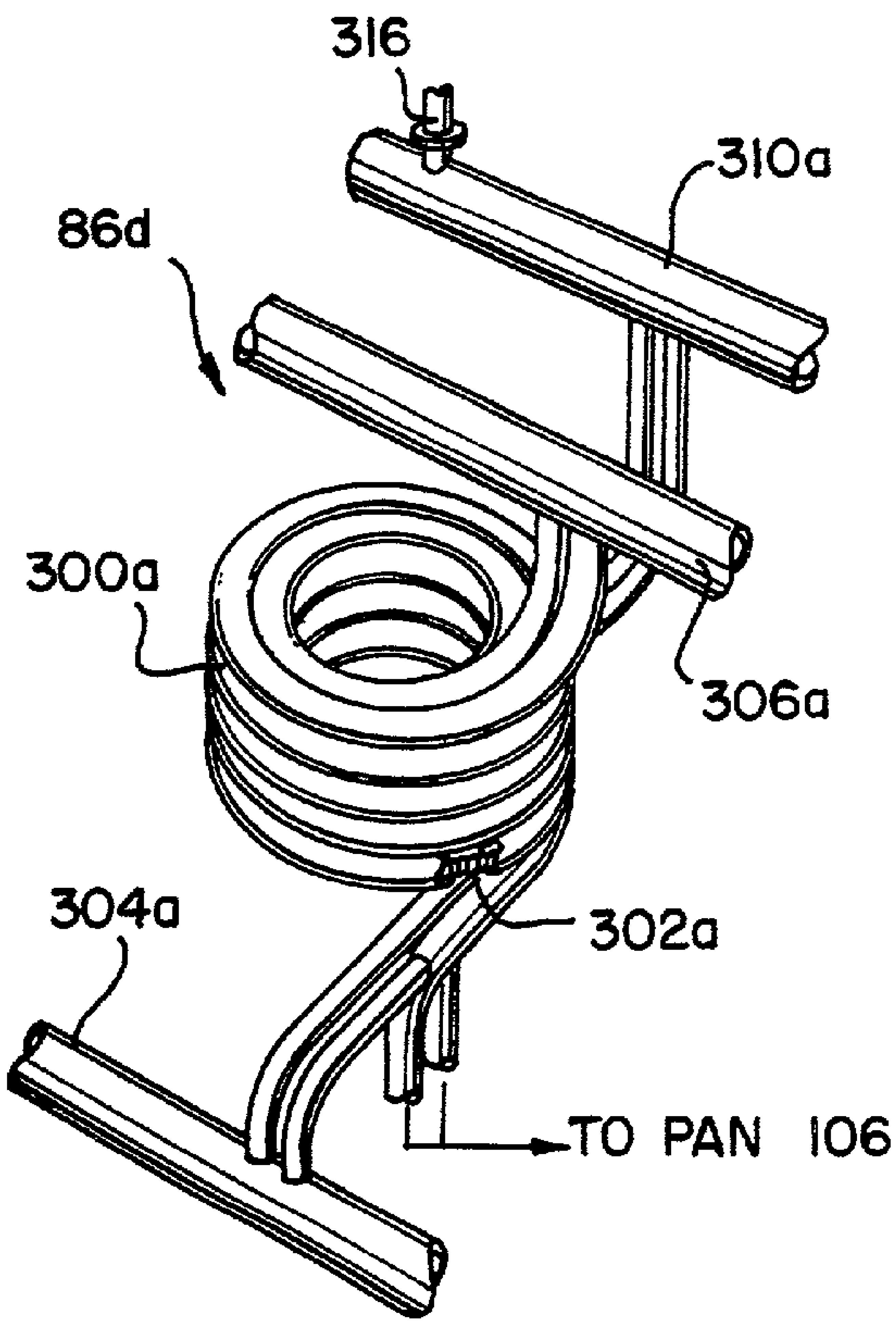

316
310a
86d
300a
306a
304a
302a
TO PAN 106

FIG. 18

FIG. 20

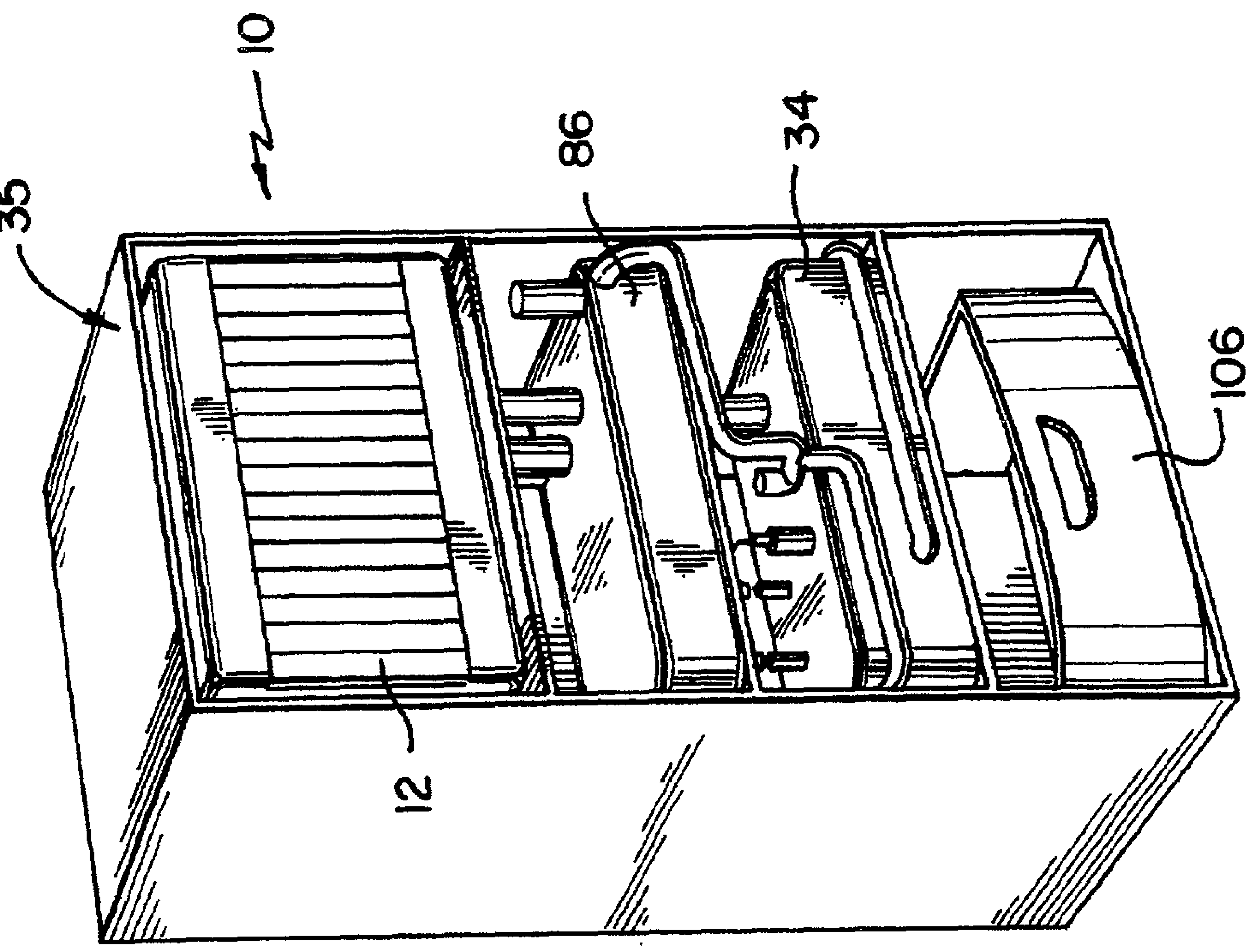
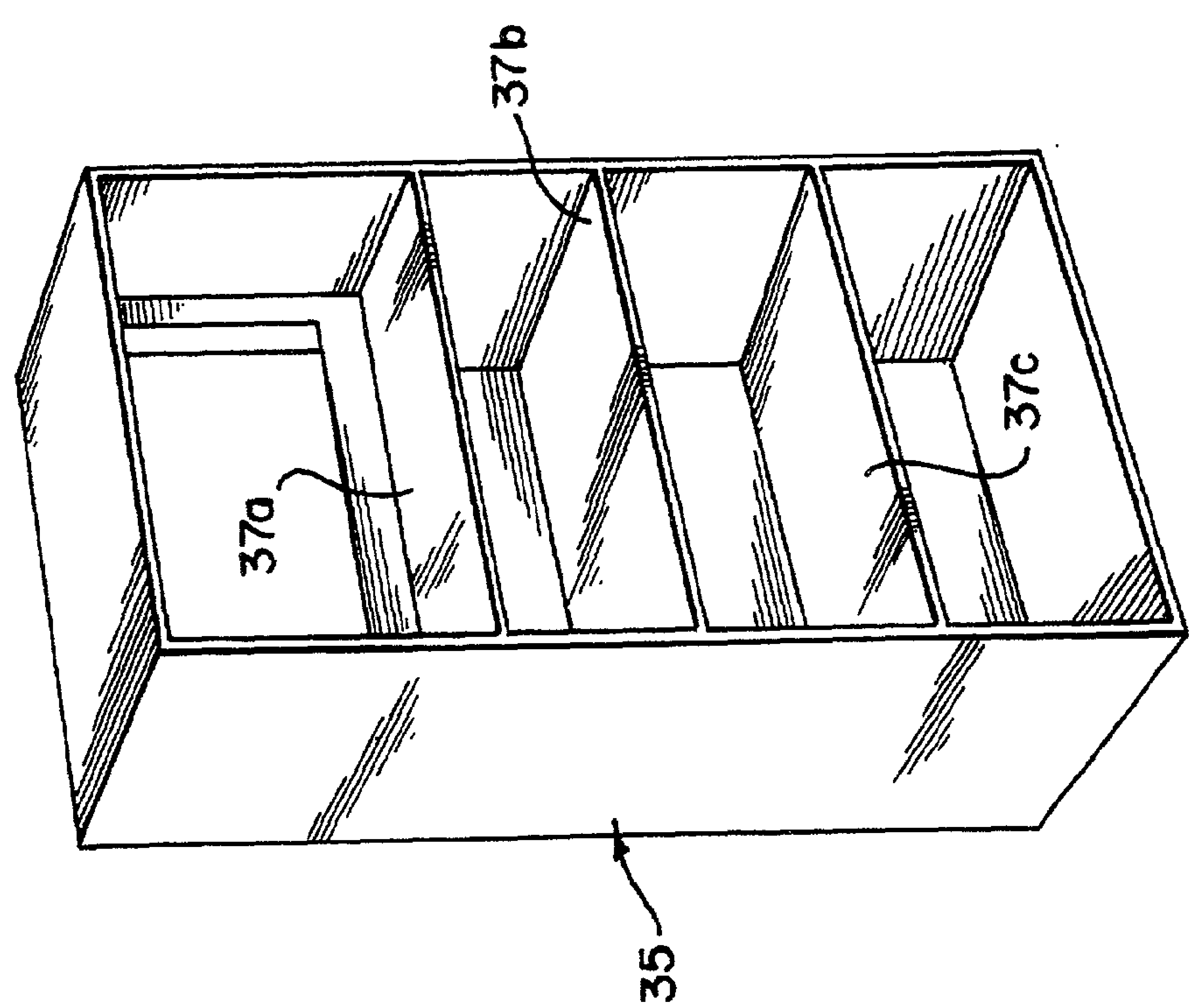


FIG. 19



LIQUID DESICCANT AIR CONDITIONER

[0001] This application is a continuation-in-part application of Appl. Ser. No. 08/984,741, filed Dec. 4, 1997.

BACKGROUND

[0002] 1. Field of the Invention

[0003] The present invention relates generally to room air cooling and dehumidification, and more particularly, to a liquid desiccant air conditioner which is energy efficient, corrosion resistant, and capable of operation with low energy usage.

[0004] 2. Description of the Prior Art

[0005] Typical air conditioning units operate on a vapor compression cycle. Over recent years, the phase out of CFC based air conditioning units has been dictated by environmental concerns. One alterative to vapor compression units, is the absorption system. The basic elements include an evaporator, condenser, absorber, pump, heat exchanger, throttle valve and regenerator. In the absorption cycle, an "absorbent" is used to absorb the refrigerant in the vaporized state after leaving the evaporator. The vaporized refrigerant is converted back into the liquid phase in the absorber. Heat released in the absorption process is rejected to cooling water passed through the absorber. A solution of absorbent and refrigerant is pumped to a regenerator, where heat is added and the more volatile refrigerant is separated from the absorbent through distillation. The refrigerant is then communicated to the condenser, expansion valve and evaporator in a conventional manner. A heat exchanger may be used for heat recovery between the absorbent returned to the absorber and the absorbent-refrigerant solution delivered to the regenerator.

[0006] Absorption systems currently represent only a small percentage of commercial refrigeration systems because they are generally bulky and inefficient.

[0007] However, with concerns over CFCs and ever increasing energy costs, the absorption unit has potential to provide efficient cooling by taking advantage of waste heat. This may be provided by combining such an absorption unit with a liquid desiccant dehumidifier.

[0008] It is known in the art to dehumidify ambient air using liquid desiccant systems. These devices typically utilize hygroscopic liquids such as lithium bromide (LiBr), lithium chloride (LiCl) or calcium chloride ($CaCl_2$) as the desiccant solution. In a desiccant system, the desiccant solution absorbs moisture from ambient air exposed to the solution. As the desiccant solution continues to absorb moisture, it becomes dilute and must be regenerated. In the regeneration process, the desiccant solution is heated to evaporate the excess moisture or the desiccant solution is brought into contact with a hot gas to desorb the excess moisture. In some expedients, air regenerators are used to regenerate the desiccant. These arrangements have relatively high operating costs as energy is required to provide a source of heat and to generate a suitable flow of air. In others, boiler-type regenerators are employed. However, boiler embodiments are expensive, as the corrosive nature of liquid desiccant solutions necessitates the use of costly corrosion resistant metals.

[0009] A liquid desiccant dehumidification system in which a liquid desiccant is regenerated with a boiler is described in U.S. Pat. No. 4,939,906 ("the '906 Patent"). The '906 Patent discloses a gas-fired desiccant boiler and a combined desiccant regenerator/interchange heat exchanger, in which the combined regenerator/heat exchanger utilizes steam produced from the boiler to provide heat for partial regeneration. The desiccant boiler has a liquid/vapor separator chamber and thermosyphon recirculation to reduce scale and corrosion of the boiler. Specifically, the overall system is shown in **FIG. 1**, wherein outdoor air is drawn into the system through an inlet duct **22**, and is evaporatively cooled by a water spray **24**. The cooled air is directed to a desiccant conditioner **26** to which return air is also directed through a duct **30**. In the desiccant conditioner **26**, the return air is contacted with a liquid desiccant solution from a sprayer **28**. The desiccant liquid is disclosed as lithium calcium chloride.

[0010] This dehumidified air is then supplied to the space to be dehumidified, or it can be sensibly cooled through an evaporative cooler **32**. The desiccant dehumidifies the air stream, and in the process its moisture-absorbing capability is reduced; this capability is regenerated by passing a portion of the dilute desiccant from the conditioner **26** to a first interchange heat exchanger **44**, wherein the temperature of the desiccant is raised. The weakened desiccant is partially concentrated in an air-desiccant regenerator **46**, in which heated air from a regeneration air heater **48** contacts the liquid desiccant. This desiccant is pumped through a second interchange heat exchanger **52** and thereafter to a desiccant boiler **56**, in which regeneration of the desiccant is completed. The water vapor generated in the desiccant boiler **56** raises the temperature of the air passing through the regeneration air preheater **48**. The interchange heat exchangers **44**, **52** reduce the temperature of the regenerated desiccant as it returns along the pipe **60** to the conditioner **26**.

[0011] The boiler **56** is depicted in **FIG. 2**, and operates on natural circulation, with the density of the fluid (part liquid, part vapor) in the "fired" tubes **70** being less than the density of the liquid in the outer "unfired" tube **74**.

[0012] A porous ceramic burner **80** facilitates combustion to provide a heat source and hot combustion gases are blown through a combustion chamber formed by a housing **88** enclosing the fired tubes **70**, and flow across fins **90** of the fired tubes **70**. Weak desiccant is pumped into the fired tubes **70** through a manifold **94** which causes water in the desiccant to be vaporized. Accordingly, a density differential is created between the fluid in the fired tubes **70** and the unfired tubes **74** connected between the manifold **94** and a liquid/vapor separator **98** outside the combustion chamber housing **88**. This density differential induces a natural flow of desiccant solution up the fired tubes **70** and down the unfired tubes **72**. In this manner, the natural circulation of desiccant keeps the inside walls of the fired tubes **70** coated with desiccant to thereby reduce or prevent "hot spots" from forming on the inside of the fired tubes **70** to reduce corrosion and scale build up in the fired tubes **70**.

[0013] The liquid vapor separator **98** at the top of the boiler **56** separates water vapor from the concentrated liquid desiccant. A portion of the concentrated desiccant is withdrawn from the bottom of the liquid/vapor separator **98** and is returned to the desiccant conditioner **26**. Water vapor flowing out of the top of the liquid/vapor separator **98** is subsequently condensed to heat air for use in an earlier regeneration step shown in **FIGS. 3 and 4**.

[**0014**] The combined regenerator/interchange heat exchanger, depicted in **FIGS. 3 and 4**, comprises two (2) interchange heat exchangers **44**, **52**, the desiccant regenerator **46** and the regeneration air heater **48**. The combined desiccant regenerator/interchange heat exchanger is identified by the reference numeral **102**, and is constructed by alternately stacking two (2) different corrugated plates (see **FIG. 4**) to define alternating flow channels. Water vapor or steam from the desiccant boiler **56** is introduced near the top of the regenerator/exchanger **102** in alternate channels (plate A). This water vapor is condensed, thereby transferring heat to the air and weak desiccant entering adjacent channels near the top of the regenerator/heat exchanger **102** (plate B).

[**0015**] The upper portion of each plate corresponds to the desiccant regenerator **46** and regeneration air heater **48**. As the water vapor condenses, the weak desiccant and air mixture is heated and the desiccant is partially regenerated. Warm air and moisture are exhausted by fan **106** to the outdoors. An entrainer **108** is provided to prevent desiccant from escaping the combined regenerator/exchanger **102**. The partially regenerated desiccant flows into the middle of a channel plate B, and is further heated by the hot concentrated desiccant removed from the liquid/vapor separator **98**. Hot concentrated desiccant from the boiler **56** is introduced at the middle of plate A while the partially regenerated desiccant is removed from the middle of plate B. The partially regenerated desiccant is then pumped to the desiccant boiler **56**. Diluted desiccant from the regenerator/heat exchanger **102** is introduced at the bottom of the plate A and is heated by the hot desiccant from the boiler **56**. The heated dilute desiccant from the regenerator/heat exchanger **102** is then removed from the center of plate B and pumped to the top of plate B.

[**0016**] The apparatus shown and described in the '906 Patent suffers from several disadvantages. The regeneration process described therein requires the flow of hot air through the system in order to operate. This necessitates the use of additional components such as fans, air preheaters, and liquid/vapor separators, which adds system complexity. Furthermore, the multiple stacked plate interchange heat exchanger configuration is complex and takes up a relatively large amount of space.

[**0017**] The present invention provides an improved air cooling system comprising an absorption air conditioner operating in conjunction with a liquid desiccant dehumidifier.

SUMMARY OF THE INVENTION

[**0018**] It is an object of the present invention to provide a liquid desiccant air conditioner which dehumidifies and cools ambient air in a combined liquid desiccant-refrigerant absorption cycle.

[**0019**] It is another object of the present invention to provide a liquid desiccant air conditioner which does not require CFCs.

[**0020**] It is a further object of the present invention to provide a liquid desiccant air conditioner which is energy efficient.

[**0021**] It is still another object of the present invention to provide a liquid desiccant air conditioner which does not require a compressor.

[**0022**] It is yet another object of the present invention to provide a liquid desiccant air conditioner which does not require any external heat input to effect regeneration of the refrigerant absorbent.

[**0023**] It is an object of the present invention to provide a liquid desiccant air conditioner which efficiently regenerates the liquid desiccant using a simple arrangement having a minimum number of components.

[**0024**] It is still another object of the present invention to provide a liquid desiccant air conditioner which utilizes primarily plastic components to prevent corrosion.

[**0025**] It is yet another object of the present invention to provide a liquid desiccant air conditioner in which steam to desiccant heat recovery takes place in a condenser.

[**0026**] It is a further object of the present invention to provide a liquid desiccant air conditioner in which plastic components are used for the interchange heat exchangers.

[**0027**] It is yet another object of the present invention to provide a liquid desiccant air conditioner in which the waste heat radiating from the boiler is utilized in an interchange heat exchanger for desiccant regeneration.

[**0028**] It is still another object of the present invention to provide a liquid desiccant air conditioner having a boiler which is primarily elongated in a horizontal orientation to minimize the temperature gradient and consequent concentration differential in the liquid desiccant.

[**0029**] It is yet another object of the present invention to provide a liquid desiccant air conditioner which is lightweight, energy efficient, and inexpensive to manufacture.

[**0030**] In accordance with the foregoing objects and additional objects that will become apparent hereinafter, the present invention provides a liquid desiccant air conditioner, including a liquid desiccant absorber for absorbing moisture contained in ambient air entering the dehumidifier and passing through the desiccant absorber, the desiccant absorber constructed and arranged for receiving concentrated liquid desiccant and dispensing dilute liquid desiccant. A boiler is provided for boiling partially preheated dilute liquid desiccant to evaporate moisture to reconstitute the liquid desiccant into concentrated liquid desiccant. A condenser fluidly communicates with the boiler to receive steam generated by boiling liquid desiccant in the boiler, and with the absorber to receive dilute liquid desiccant from the absorber. The condenser is operable to sensibly heat the dilute liquid desiccant therein by recovering the latent heat of condensation as steam delivered from the boiler is condensed, to preheat the dilute liquid desiccant prior to delivery to the boiler to increase operating efficiency. An evaporator effects cooling of dehumidified air delivered from the desiccant absorber. A refrigerant is vaporized in the evaporator and passed to a refrigerant absorber which contains an absorbent solution such as, for example, ammonia-water or water-lithium bromide. The refrigerant-absorber solution is pumped to a regenerator in which the refrigerant is separated from the absorbent. The regenerator fluidly communicates with the boiler to receive steam from the boiler as a heat input to effect regeneration. A second condenser receives the reconstituted refrigerant from the regenerator. The refrigerant passes through the second condenser, and from there through an expansion valve and into the evaporator in a conventional manner. A heat exchanger may be used to recover heat from the absorbent as it is returned to the refrigerant absorber to preheat the refrigerant-absorbent solution prior to introduction of the solution into the regenerator.

[**0031**] In a preferred embodiment, the invention provides a liquid desiccant air conditioner including a liquid desiccant absorber for absorbing moisture contained in ambient air entering the dehumidifier and passing through the desiccant absorber, the desiccant absorber constructed and arranged for receiving concentrated liquid desiccant and dispensing dilute liquid desiccant. A boiler is provided for boiling partially preheated dilute liquid desiccant to evaporate moisture to reconstitute the liquid desiccant into concentrated liquid desiccant. A first heat exchanger fluidly communicates with the desiccant absorber and a second heat exchanger. The first heat exchanger is operable to transfer heat from the concentrated liquid desiccant to the dilute liquid desiccant directed to the first heat exchanger from the desiccant absorber to raise the temperature of the dilute liquid desiccant to a first temperature. A condenser fluidly communicates with the boiler to receive steam generated by boiling the liquid desiccant in the boiler, and with the first heat exchanger to receive partially heated dilute liquid desiccant from the first heat exchanger at the first temperature. The condenser is operable to sensibly heat the dilute liquid desiccant therein to a second temperature by recovering the latent heat of condensation as steam delivered from the boiler is condensed. The second heat exchanger fluidly communicates with the condenser, the boiler and the first heat exchanger. The second heat exchanger is operable to transfer heat from concentrated liquid desiccant directed to the second heat exchanger from the boiler to the dilute liquid desiccant directed to the second heat exchanger from the condenser at the second temperature to raise the temperature of the dilute liquid desiccant to a third temperature. The dilute liquid desiccant at the third temperature is directed to the boiler and the concentrated liquid desiccant from the second heat exchanger is directed to the first heat exchanger. The second heat exchanger is disposed with respect to the boiler to recover waste heat from the boiler. A pump is provided for pumping concentrated liquid desiccant into the absorber. An evaporator effects cooling of dehumidified air delivered from the desiccant absorber. A refrigerant is vaporized in the evaporator and passed to a refrigerant absorber which contains an absorbent solution such as, for example, ammonia-water or water-lithium bromide. The refrigerant-absorber solution is pumped to a regenerator in which the refrigerant is separated from the absorbent. The regenerator fluidly communicates with the boiler to receive steam from the boiler as a heat input to effect regeneration. A second condenser receives the reconstituted refrigerant from the regenerator. The refrigerant passes through the second condenser, and from there through an expansion valve and into the evaporator in a conventional manner. A heat exchanger may be used to recover heat from the absorbent as it is returned to the refrigerant absorber to preheat the refrigerant-absorbent solution prior to introduction of the solution into the regenerator.

[**0032**] In a preferred embodiment, the desiccant absorber includes a top and a bottom and comprises: a plurality of horizontally and vertically disposed interconnected microglass fiber plates; a distributor disposed above the fiber plates at the top of the desiccant absorber for introducing the concentrated desiccant into the desiccant absorber; and a drain pan for collecting the dilute desiccant disposed at the bottom of the desiccant absorber.

[**0033**] The first heat exchanger comprises at least one tube assembly including an inner tube concentrically disposed within an outer tube to define an annulus therebetween. The dilute liquid desiccant from the desiccant absorber is passed through the inner tube, and the concentrated liquid desiccant is passed through the annulus, or vice-a-versa.

[**0034**] The second heat exchanger comprises at least one tube assembly including an inner tube concentrically disposed within an outer tube to define an annulus therebetween. The tube assembly is coiled around the boiler to recover waste heat passing through the walls of the boiler. The concentrated liquid desiccant from the boiler is passed through the annulus and the partially heated dilute liquid desiccant from the condenser is passed through the inner tube, or vice-a-versa.

[**0035**] In a preferred embodiment, the inner tubes of the heat exchangers are fabricated from Teflon and the outer tubes are fabricated from silicone rubber.

[**0036**] The inner tubes may be convoluted or corrugated to increase the available heat transfer area.

[**0037**] In a preferred embodiment, the condenser comprises an inner shell disposed within an outer housing defining at least one chamber between the inner shell and the housing. Steam is directed to the inner shell from the boiler through a steam inlet. The housing includes a solution inlet to direct partially heated dilute liquid desiccant from the first heat exchanger into the at least one chamber. A solution outlet communicates with the chamber and directs partially heated dilute desiccant at the second temperature to the second heat exchanger. The inner shell is fabricated from materials including inconel, monel, titanium, Teflon, Teflon-coated copper, Teflon-coated aluminum, and Teflon-coated stainless steel; and the outer shell is fabricated from materials including Teflon, polycarbonate, polyvinylidene fluoride, polypropylene, silicone rubber, polyethylene, and polystyrene.

[**0038**] In an alternative embodiment, the condenser comprises at least one steam inlet communicating steam from the boiler with the at least one chamber and at least one solution inlet communicating partially heated dilute liquid desiccant from the first heat exchanger with the inner shell.

[**0039**] The condenser may incorporate a plurality of fins associated with the inner shell and a plurality of fins associated with the housing. The inner shell may be provided with a plurality of baffles to prevent short circuiting from the steam inlet to the condensate outlet.

[**0040**] In another embodiment, the condenser comprises a housing and a plurality of convoluted tubes. The tubes are supported by opposing support plates, and communicate with a steam inlet to receive steam from the boiler. The housing includes a solution inlet to receive partially heated dilute liquid desiccant from the first heat exchanger, and a solution outlet through which partially heated dilute liquid desiccant is delivered to the second heat exchanger. The tubes are fabricated from Teflon, and the support plates include at least one silicone rubber sheet attached thereto.

[0041] In a preferred embodiment, the respective components are disposed with respect to one another to take advantage of gravity feed to communicate the liquid desiccant from the absorber to the boiler via the first and second heat exchangers and the condenser, thereby eliminating the need for multiple pumps in the system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0042] In accordance with the above, the present invention will now be described in detail with particular reference to the accompanying drawings.

[0043] **FIG. 1** is a schematic of a first embodiment of a liquid desiccant air conditioner in accordance with the present invention;

[0044] **FIG. 2** is a schematic of a second embodiment of a liquid desiccant air conditioner in accordance with the present invention;

[0045] **FIG. 3** is a schematic of a third embodiment of a liquid desiccant air conditioner in accordance with the present invention;

[0046] **FIG. 4** is a schematic of a fourth embodiment of a liquid desiccant air conditioner in accordance with the present invention;

[0047] **FIG. 5** is a schematic of a fifth embodiment of a liquid desiccant air conditioner in accordance with the present invention;

[0048] **FIG. 6** is a schematic of a sixth embodiment of a liquid desiccant air conditioner in accordance with the present invention;

[0049] **FIG. 7** is a schematic of a seventh embodiment of a liquid desiccant air conditioner in accordance with the present invention;

[0050] **FIG. 8** is an exploded isometric view of the portable liquid desiccant dehumidifier in accordance with the present invention;

[0051] **FIG. 8A** is a block diagram depicting the general operation of the liquid desiccant dehumidifier;

[0052] **FIG. 9** is an exploded isometric view of a desiccant absorber assembly;

[0053] **FIG. 9A** is a detail view of the microglass fiber plates in the absorber;

[0054] **FIG. 9B** is a side elevational view of a desiccant absorber in another embodiment;

[0055] **FIG. 9C** is a detail view of the absorber pads;

[0056] **FIG. 9D** is an isometric view of the desiccant absorber of **FIG. 9B**;

[0057] **FIG. 10** is an isometric view of a boiler;

[0058] **FIG. 11** is an isometric view of a coiled interchange heat exchanger and the boiler;

[0059] **FIG. 11A** is an isometric view of a boiler in an alternative embodiment;

[0060] **FIG. 12** is an isometric view of a split interchange heat exchanger;

[0061] **FIG. 12A** is a plan view of an inner tube for an interchange heat exchanger having a convoluted profile;

[0062] **FIG. 12B** is a plan view of an inner tube for an interchange heat exchanger having a corrugated profile;

[0063] **FIG. 13** is an isometric cut-away view of a condenser in a first embodiment;

[0064] **FIG. 14** is an isometric cut-away view of an inner shell of the condenser shown in **FIG. 13**;

[0065] **FIG. 15** is an isometric cut-away view of a condenser in a second embodiment;

[0066] **FIG. 16** is an isometric cut-away view of a condenser in a third embodiment;

[0067] **FIG. 17** is an isometric view of a condenser in a fourth embodiment;

[0068] **FIG. 18** is an isometric view of a condenser is a fifth embodiment;

[0069] **FIG. 19** is an isometric cut-away view of a frame for housing the respective components of the system; and

[0070] **FIG. 20** is an isometric cut-away view depicting the frame and some of the components installed therein.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0071] Referring to the several views of the drawings, there is shown a liquid desiccant air conditioner ("LDA"), generally characterized by the reference numeral **10**.

[0072] **FIG. 1** is a schematic of the LDA **10** in a first embodiment. The LDA **10** is principally comprised of a liquid desiccant dehumidifier **200** and an absorption air conditioner **202**. The details of the liquid desiccant dehumidifier **200** are described in detail below and are the same as disclosed in U.S. Appl. Ser. No. 08/984,741 to the same assignee, filed Dec. 4, 1997. The liquid desiccant dehumidifier **200** primarily includes an absorber **12**, condenser, **86**, and boiler **34**. An interchange heat exchanger **58** is disposed between boiler **34** and condenser **86**, and a split interchange heat exchanger **66** is located between condenser **86** and absorber **12**. These components are described below. Specifically, the LDA **10** dehumidifies incoming ambient air prior to effecting sensible cooling of the air in the air conditioner **202**. The absorption cycle employs waste heat generated by the boiler **34** of liquid desiccant dehumidifier **200** for energy efficient cooling and dehumidification. The air conditioner **202** employs the known absorption cycle, and includes an absorber **204**, a pump **206**, a heat exchanger **208**, at throttle valve **210**, a regenerator **212**, an evaporator **214**, a condenser **216**, and an expansion valve **218**. In the absorption cycle, an absorbent, such as aqueous ammonia or aqueous lithium bromide, is used to absorb refrigerant in the vaporized state after leaving evaporator **214**. The vaporized refrigerant is absorbed back into the liquid phase in absorber **204**. Heat released in the absorption process is rejected to cooling water or air passed through absorber **204**. A solution of absorbent and refrigerant is pumped to regenerator **212**, where heat is added and the more volatile refrigerant is separated from the absorbent. The refrigerant is then communicated to condenser **216**, through expansion valve **218** and into the evaporator **214** in a conventional manner. A heat exchanger **208** may be used for heat recovery between the warm absorbent returned to the absorber **204** through throttle valve **210**, and the absorbent-refrigerant solution delivered from the absorber **204** to the regenerator **212** via pump **206**. The regenerator **212** fluidly communicates with boiler **34** to receive steam generated in reconstituting the liquid desiccant as described below. In this manner, no external heat input is required to regenerate the refrigerant. The heat exchanger **208** can configured as described below with respect to interchange heat exchanger **66** of the liquid desiccant dehumidifier **200**.

[**0073**] **FIG. 2** is a schematic of a second embodiment of the LDA **10**, which adds an indirect evaporative cooler **220** for cooling the incoming air with exhaust air from the residence prior to passing the incoming air through the desiccant absorber **12**. The indirect evaporator cooler **20** receives a water supply from condenser **86** and regenerator **212**. Fresh air is directed into the cooler **220** from the ambient, cooled, and thereafter delivered to desiccant absorber **12**. The remainder of the cycle operates as described above.

[**0074**] **FIG. 3** is a schematic of a third embodiment of the LDA **10**, which adds a direct evaporative cooler **222** to the embodiment of **FIG. 2**. The direct evaporative cooler **222** is operable to further cool the air prior to delivery to the ambient. Water is supplied to cooler **222** from condenser **86** and regenerator **212**. **FIG. 4** is a schematic of a fourth embodiment of the LDA **10**, in which the ambient air is first directed into the absorber **12** for dehumidification, and then into the indirect evaporative cooler **220** for cooling. **FIG. 5** is a schematic of a fifth embodiment of the LDA **10**, which is similar to that shown in **FIG. 1**, but adds the direct evaporative cooler **222**.

[**0075**] **FIG. 6** is a schematic of a sixth embodiment of the LDA **10** which does not utilize a refrigerant. In this expedient, the LDA **10** cooperates with an indirect evaporative cooler **220** and a direct evaporative cooler **222** to cool and dehumidify the incoming air. The air is directed through indirect evaporative cooler **220**, cooled, and thereafter delivered to the desiccant absorber **12**. The dehumidified air is then passed through the direct evaporative cooler **222**, where it is further cooled by sensible cooling, and exhausted to the ambient. The principle of operation is generally the same as described above. Water from condenser **86** is delivered to indirect evaporative cooler **220** and direct evaporative cooler **222**. Exhaust air from the residence is communicated to the indirect evaporative cooler **220**. **FIG. 7** is a schematic of a seventh embodiment of the LDA **10**, which is similar to that shown in **FIG. 6** and described above, but here the incoming ambient air is first dehumidified in the desiccant absorber **12**, and thereafter cooled in the indirect evaporative cooler **220**.

[**0076**] Referring now to **FIGS. 8 and 8**A, the desiccant dehumidifier section **100** includes liquid desiccant absorber **12** for absorbing moisture contained in air entering air conditioner **10** and passing through desiccant absorber **12**. The desiccant absorber **12** is constructed and arranged for receiving concentrated liquid desiccant at the top of desiccant absorber **12** and dispensing dilute liquid desiccant from the bottom of desiccant absorber **12**. The desiccant solution may be any one of several conventional solutions, including aqueous LiBr, LiCl or $CaCl_2$, as described above, or any mixture of these solutions. Referring now to **FIGS. 9 and 9**A, desiccant absorber **12** includes a distributor **14** disposed at the top of desiccant absorber **12** which receives concentrated liquid desiccant and delivers the liquid desiccant through a plurality of "spaghetti" tubes **16** extending radially outward from a central hub **18**. The desiccant absorber **12** includes a plurality of horizontally and vertically disposed interconnected microglass fiber plates. The vertical plates are identified by the reference numeral **20**, and are supported by horizontal interconnecting fiber plates **22** as shown. The top plate **22** is referred to as a distribution sheet. The concentrated desiccant wicks into the distribution sheet **22** and down the vertical plates **20**. The vertical plates **20** contain beads **21** which separate and support contiguous vertical plates **20**. Ambient air is drawn into the unit and forced through the microglass fiber plates by a fan **23** (see **FIG. 8**), where the moisture in the air is removed as the air makes contact with the liquid desiccant. As the desiccant dehumidifies the air stream, the moisture-absorbing capability of the desiccant is reduced and the desiccant must be regenerated. This dilute desiccant is collected in a drain pan **24** disposed at the bottom of desiccant absorber **12**. The drain pan **24** includes an intermediate support plate **26** defining at least one drain hole **28** which enables the dilute desiccant to flow into a bottom chamber defined between support plate **26** and a bottom wall **30** of drain pan **24**. A drain tube **32** including a one-way or check valve **33** extends from the bottom chamber to direct the dilute desiccant out of absorber **12**. The absorber components are disposed within a frame **35** as shown in **FIG. 19**, which can be fabricated from materials including, but not limited to, polypropylene, polyethylene, Teflon, polyvinylidene fluoride, polycarbonate, PVC or polystyrene. The frame **35** includes a plurality of shelves **37***a*, **37***b*, and **37***c* for supporting the respective components of the unit described below.

[**0077**] In an alternative embodiment shown in FIGS. 9B-9D, a plurality of absorber pads **20***a* are stacked side-by-side and bonded together at the ends with an adhesive "A" (or taped) so that the gaps between the pads **20***a* are completely sealed to force the liquid desiccant to wick through the pads **20***a*. The pads **20***a* are received in an aperture or slots in a top tray or distributor pan **25** and a bottom tray or drain pan **27**. Any gaps between the pads **20***a* and the pans **25**, **27** may be filled with an RTV silicone sealant or like material. Liquid desiccant is communicated into the distributor pan **25** through an inlet **29**. This configuration prevents the liquid desiccant from just flowing over the surface of the pads, and consequently increases absorber efficiency. The trays **25**, **27** effectively prevent spillage of liquid desiccant from the absorber **12** in the event of tilting. In addition, the liquid desiccant supplied to the distributor pan **25** forms a thin film on the pan surfaces to reach every distributor pad **20***a* to improve desiccant distribution.

[**0078**] The dilute liquid desiccant is regenerated into concentrated desiccant by boiling the liquid desiccant in a boiler **34** at a temperature in the range of from approximately 260° F. to 320° F. An improvement over prior art systems resides in the use of steam to desiccant heat recovery to directly preheat the dilute liquid desiccant. The dilute liquid desiccant is thus passed through a condenser and preheated using the latent heat of condensation of the steam produced by boiling the liquid desiccant. Preferably, a series of interchange heat exchangers are employed to further preheat the dilute liquid desiccant entering the boiler **34** by recovering heat from the concentrated liquid desiccant delivered to absorber **12** from boiler **34** to further increase operating efficiency. These components are described in more detail below.

[**0079**] The boiler **34** is shown in **FIG. 10**, and is configured in the shape of a tub or vessel having an elongated horizontal dimension. The horizontal elongation provides a uniform temperature gradient, and thus a uniform concentration level of the liquid desiccant solution, as compared to a vertically elongated boiler. The boiler **34** includes side walls **36**, a bottom wall **38**, a top wall **40**, and a peripheral support flange **42**. The boiler **34** is constructed from materials including, but not limited to, polycarbonate, polyvinylidene fluoride, Teflon, fiber glass and the like. A heating element **44** is coiled proximal to the bottom wall **40** as shown, and is connected to a pair of leads **46** in a conventional manner. A thermocouple **48** extends into boiler **34** to monitor the internal temperature. The leads **46** and thermocouple **48** extend through top wall **40**. The heating element **44** and thermocouple **48** are operably associated with a controller (not shown) for maintaining boiler **34** at the optimum temperature. A pair of steam outlets **50** extend through top wall **40** to deliver steam generated by boiling the liquid desiccant to a condenser described in more detail below.

[**0080**] Referring now to **FIG. 11, a** drain tube **51** is coupled to one of the side walls **36** to enable boiler **34** to be emptied as required. A U-fitting **52** is coupled to the upper region of one of the side walls **36** to receive preheated dilute liquid desiccant from the condenser through an inlet port **54**, and to dispense concentrated liquid desiccant through an outlet port **56**. The U-fitting **52** communicates with a coiled interchange heat exchanger **58**, which comprises at least one tube assembly including an inner tube **60** concentrically disposed within an outer tube **62** to define an annulus **64** therebetween. The tube assembly is coiled around boiler **34** to recover the waste heat radiating through side walls **36**. This arrangement is exemplary, as the tube assembly could be embedded within the side walls **36**, or disposed in contact with top wall **40**. The concentrated liquid desiccant from boiler **34** enters the annulus **64** through side wall **36** and is directed to outlet port **56**. The partially heated dilute liquid desiccant from the condenser is passed through the inner tube **60** in a direction counter to the concentrated liquid desiccant and enters boiler **34** through side wall **36**.

[**0081**] Alternatively, the concentrated liquid desiccant is passed through inner tube **60** and the dilute liquid desiccant is passed through annulus **64**. In a preferred embodiment, inner tube **60** is fabricated from Teflon, and outer tube **62** is constructed from silicone rubber. The Teflon inner tube **60** has relatively high heat conductivity, while the outer silicone rubber tube **62** has a relatively low thermal conductivity, and is a good insulator. These components can withstand relatively high temperatures (~400° F.), and are not corroded by the desiccant solution. To improve efficiency, inner tube **60** may be convoluted as shown in **FIG. 12A** or corrugated as shown in **FIG. 12B**. It is to be understood that the use of this type of Teflon/silicone rubber tube-in-tube heat exchanger is not limited to a liquid desiccant system. There are many applications in which this arrangement may be employed. The particular operation of the coiled interchange heat exchanger **58** will be described in more detail below.

[**0082**] Referring now to **FIG. 11**A, there is shown an isometric view of an boiler **34***a* in an alternative embodiment, having a double-wall configuration including an inner wall **400** and an outer wall **402** which define an inner vessel **404** and an outer vessel **406**. A heating element **408** extends into the inner vessel **404** and around the floor as shown. The incoming liquid desiccant from condenser **86** enters the outer vessel **406** of the boiler at inlet **410**. Hot liquid desiccant from the inner vessel **404** is communicated into pipe **412** which coils through the outer vessel **406** to effect heat transfer with the incoming liquid desiccant. The desiccant puddle contained in the outer vessel **406** is heated and the hottest portion of the liquid is forced to rise to the top of the vessel **406**. It is then fed into the inner vessel **404** via an inlet **414**. A thermocouple **416** is disposed in the inner vessel **404** as described above to control the boiler temperature. This arrangement forces any heat radiated or conducted from the inner vessel **404** to flow through the desiccant puddle in the outer vessel **406**, thereby reducing thermal losses, and pressure losses attributable to long flow paths. The heating element **408** is disposed below the pump suction or inner vessel boiler outlet **415***a* so that heating element **408** is always immersed in a pool of liquid desiccant within the inner vessel **404**. In this manner, the pump **80** stops drawing liquid desiccant from inner vessel **404** before it is reduced to a level beneath the heating element **408**. Hot liquid desiccant leaves the boiler through outlet **415***b*. This arrangement eliminates the need for a low-level control switch. High level control in the boiler is necessary to provide consistent dehumidification and to prevent excess liquid buildup. A high level control switch can be eliminated by sizing the inner vessel **404** with an internal volume equal to approximately twice the volume of pooled liquid desiccant accumulation. This takes advantage of the inherent desiccant properties to make the system flexible to adapt to varying weather conditions without compromising performance.

[**0083**] Referring now to **FIG. 12**, there is depicted a split interchange heat exchanger **66**, which includes a pair of tube assemblies **68**. Each tube assembly **68** comprises an inner tube **70** concentrically disposed within an outer tube **72** to define an annulus **74** therebetween. The dilute liquid desiccant from desiccant absorber **12** is gravity fed to the interchange heat exchanger **66**, where it is directed through a manifold **76** and into the inner tubes **70**. Concentrated liquid desiccant from boiler **34** is first delivered through coiled interchange heat exchanger **58** and thereafter directed through a U-fitting **78** coupled to the respective outer tubes **72** and into the annuli **74**. Alternatively, dilute liquid desiccant is passed through annuli **74** and concentrated liquid desiccant is passed through inner tubes **70**. In this manner, heat is transferred from the concentrated liquid desiccant to the dilute liquid desiccant within split interchange heat exchanger **66**. The concentrated liquid desiccant is thereafter drawn into a pump **80** (see **FIGS. 8 and 8**A) through a U-fitting **82** coupled to the respective outer tubes **72**. The pump **80** delivers the concentrated liquid desiccant to distributor **14** of absorber **12**. The partially heated dilute liquid desiccant flows through a manifold **84** to the condenser. During this stage, the dilute liquid desiccant dispensed from absorber **12** is raised to a first temperature. As discussed above with respect to coiled interchange heat exchanger **58**, the inner tubes **70** may be fabricated from Teflon and the outer tubes **72** may be constructed from silicone rubber. Likewise, the inner tubes may be provided with a convoluted or corrugated profile as shown in **FIGS. 12A and 12B**, respectively.

[**0084**] The partially heated liquid desiccant at the first temperature is delivered to a condenser **86** from split interchange heat exchanger **66** as shown in **FIGS. 8 and 8**A. Referring now to **FIGS. 13 and 14**, there is depicted a first embodiment of condenser **86**, which is comprised of an inner shell **88** disposed within an outer housing **90** defining at least one chamber **92** between inner shell **88** and housing **90**. The housing **90** includes a plurality of side walls **94**, a top wall **96** and a bottom wall **98**. A pair of steam tubes **100** communicate with inner shell **88** through top wall **96** to deliver steam from boiler **34**. A pair of air vents **102** likewise communicate with chamber **92** through top wall **96** to evacuate excess air therefrom. A condensate tube **104** communicates with inner shell **88** through bottom wall **98** to drain condensate into a condensate pan **106** (see **FIG. 8A**). An inlet tube **108** communicates with chamber **92** through one of the side walls **94** to deliver partially heated dilute desiccant to condenser **86** from split interchange heat exchanger **66**. An outlet tube **110** is similarly disposed to communicate with chamber **92** on an opposite side of condenser **86** to deliver dilute desiccant which is sensibly heated to a second temperature by the latent heat of condensation as the steam condenses in the inner shell **88**, to the coiled interchange heat exchanger **58** via the inlet port **54** of U-fitting **52** shown in **FIGS. 8 and 11**. A fraction of the desiccant flow leaving the condenser may be recirculated to the desiccant absorber **12**. This reduces the flow rate to the boiler **34** to lower heat loss and increase energy efficiency. In addition, this maintains a relatively high flow through the absorber **12** and condenser **86** to yield a higher absorption and condensation capacity. To facilitate heat transfer, inner shell **88** is fabricated from materials including inconel, monel, titanium, Teflon, Teflon-coated copper, Teflon-coated aluminum, and Teflon-coated stainless steel. The housing **90** is fabricated from materials including Teflon, polycarbonate, polyvinylidene fluoride, polypropylene, silicone rubber, polyethylene, and polystyrene. If a plastic such as Teflon is used for the housing **90**, the wall thickness is made suitably thick to provide the necessary insulating properties.

[**0085**] The condenser **86** may incorporate a plurality of fins **112** located on the exterior of inner shell **88** and a plurality of fins **114** disposed on bottom wall **98** of housing **90**. The inner shell **88** may be provided with a plurality of baffles **116** to prevent short circuiting from steam inlets **100** to condensate outlet **104**.

[**0086**] Although depicted with the steam being directed into the inner shell **88** and the liquid desiccant being directed into the chamber **92**, the opposite arrangement may be employed with the liquid desiccant directed into the inner shell **88** and the steam delivered to the chamber **92**. Referring now to **FIG. 15**, there is shown an alternative embodiment of a condenser **86***a*, including a housing **90***a* and inner shell **88***a*, where the inner shell **88***a* segregates housing **90***a* into two compartments **92***a*, **92***b*, respectively. A steam inlet tube **100***a* communicates with compartment **92***a*, and a steam inlet tube **100***b* communicates with compartment **92***b*. Partially heated dilute desiccant solution is delivered to inner shell **88***a* through solution inlet **108***a*, and is sensibly heated by the latent heat of condensation as the steam condenses in the respective chambers **92***a*, **92***b*.

[**0087**] Condensate flows out of chambers **92***a*, **92***b*, via condensate outlets **104***a*, **104***b*, respectively. Partially heated dilute desiccant at the second temperature flows out of inner shell **88***a* through solution outlet **110***a* to coiled interchange heat exchanger **58**. Baffles **112***a*, **112***b* are provided in chambers **92***a*, **92***b*, respectively.

[**0088**] Referring now to **FIG. 16**, there is shown a third embodiment of a condenser **86***b*, comprising a housing **90***b* and a plurality of tubes **118**, which may be convoluted or corrugated as described above with regard to the interchange heat exchangers and shown in **FIGS. 12A and 12B**. The tubes **118** are supported by opposing support plates **120** and communicate with respective steam inlets **100***c*, **100***d* through which steam is delivered from boiler **34**. The housing **90***b* includes a liquid desiccant solution inlet **108***b* to receive dilute liquid desiccant from split interchange heat exchanger **66**, and an outlet **110***b* to deliver partially heated liquid desiccant at the second temperature to the coiled **10** interchange heat exchanger **58**. The tubes **118** are fabricated from Teflon, and the support plates **120** include at least one silicone rubber sheet attached thereto.

[**0089**] Referring now to **FIG. 17**, there is shown another embodiment of a condenser **86***c*, utilizing multiple double-pipe heat exchangers. Each double-pipe heat exchanger comprises an outer straight tube **300** and an inner convoluted tube **302** concentrically disposed within the outer tube. A small annular gap is defined between the outer and inner tubes **300, 302** which forces the fluid to follow a "screw-like" tortuous path through the convolutions at high velocity. This arrangement provides high heat transfer coefficients and condensation capacity. The components can be fabricated from plastics such as polypropylene, Teflon, PVDF or silicone rubber. Dilute liquid desiccant from split Interchange heat exchanger **66** is directed into a manifold **304**. Similarly, steam from boiler **34** flows into a manifold **306** through inlet ports **308**. Manifold **304** communicates with the inner convoluted tubes **302**. Steam flows through the annuli formed between outer tubes **308** and inner tubes **302,** causing the dilute liquid desiccant entering the heat exchangers from manifold **304** to be partially heated to the second temperature. This heated liquid desiccant is delivered to the coiled interchange heat exchanger **58** from exit manifold **310**. Condensate is collected in manifold **312**, and is then delivered to pan **106**. Air vents are utilized to ensure reliable gravity assisted drain flow of the liquid desiccant from the absorber **12** to the boiler **34**. In a preferred embodiment, small pieces of Teflon tape having a micro-pore structure can be used in the vent assembly. The Teflon material is hydrophobic and has a micro-pore structure which enables the free passage of air while preventing steam or desiccant leakage. The air vent **314** comprises a tube **316** extending upwardly from manifold **310**. The tube **316** includes a polypropylene mesh **318** and a piece of Teflon tape **320** in a laminated structure. Alternatively, conventional float-based air vents, such as air vents manufactured by Honeywell, can be utilized to vent air from the system.

[**0090**] Referring now to **FIG. 18**, in another embodiment the condenser **86***d* comprises multiple coiled double pipe heat exchangers. Each double pipe heat exchanger includes an outer straight tube **300***a* and inner convoluted tube **302***a* concentrically disposed within the outer tube **300***a*. Steam from boiler **34** enters a manifold **306***a*, from where it is communicated into the annuli formed between outer tubes **300***a* and inner tubes **302***a*. Dilute liquid desiccant is delivered to manifold **304***a* and thence into the inner tubes **302***a*. Partially heated liquid desiccant exits into manifold **310***a*, and is delivered to coiled Interchange heat exchanger **58**. Condensate flows through outlets **312***a* to pan **106**. This condenser **86***d*, operates on the same principles and offers the same advantages as the double-pipe condenser **86***c* described above.

[**0091**] Referring now to **FIG. 20**, the respective components of the LDA **10** are shown stacked within frame **35** (the components of the absorption air conditioner **202** are not shown).

[**0092**] During the operating cycle, ambient air is drawn into the unit, through absorber **12** and exhausted to the room by fan **23**. The moisture in the air is extracted as the air makes contact with the liquid desiccant wicking across the microglass fiber wick plates **20**, **22**. Dilute liquid desiccant is gravity fed from drain pan **24** of absorber **12** to manifold **76** of split interchange heat exchanger **66**, wherein it is raised to a first temperature through heat transfer from concentrated liquid desiccant flowing through annuli **74**. The dilute liquid desiccant at the first temperature is then delivered to the condenser **86**, in which the latent heat of condensation as the steam condenses sensibly heats the liquid desiccant to the second temperature. The liquid desiccant at the second temperature is thereafter delivered to the coiled interchange heat exchanger **58** in which it is further heated to a third temperature prior to introduction into boiler **34** for regeneration. The coiled interchange heat exchanger **58** recovers waste heat radiating from the walls **36** of boiler **34**. The concentrated liquid desiccant solution produced by boiling the liquid desiccant is drawn through the coiled interchange heat exchanger **58** and split interchange heat exchanger **66**, and thereafter delivered to distributor **14** of absorber **12** by pump **80**. The stacking of the respective components as shown in **FIG. 8** provides for the gravity feed of dilute liquid desiccant from absorber **12** to boiler **34** through the first and second heat exchangers and the condenser, thereby eliminating the need for multiple pumps in the system.

[**0093**] The present invention has been shown and described in what are considered to be the most practical and preferred embodiments. It is anticipated, however, that departures can be made therefrom and that obvious modifications will be implemented by persons skilled in the art.

1. A liquid desiccant air conditioner, comprising:

a liquid desiccant absorber for absorbing moisture contained in ambient air entering the dehumidifier and passing through said desiccant absorber, said desiccant absorber constructed and arranged for receiving concentrated liquid desiccant and dispensing dilute liquid desiccant;

a boiler for boiling partially preheated dilute liquid desiccant to evaporate moisture to reconstitute the liquid desiccant into concentrated liquid desiccant;

a first condenser fluidly communicating with said boiler to receive steam generated by boiling liquid desiccant in said boiler, said first condenser further fluidly communicating with said absorber to receive dilute liquid desiccant from said absorber, said first condenser being operable to sensibly heat the dilute liquid desiccant therein by recovering the latent heat of condensation as steam delivered from said boiler is condensed, to preheat said dilute liquid desiccant prior to delivery to said boiler;

a second condenser;

an evaporator through which a refrigerant is passed to effect cooling of dehumidified ambient air from said desiccant absorber passing through said evaporator;

an expansion valve disposed between said condenser and said evaporator;

a refrigerant absorber fluidly communicating with said evaporator to receive vaporized refrigerant from said evaporator, said refrigerant absorber containing an absorbent for absorbing the vaporized refrigerant;

a regenerator for separating refrigerant from the absorbent, said regenerator fluidly communicating with said second condenser to supply separated refrigerant to said second condenser, said regenerator fluidly communicating with said refrigerant absorber to receive a solution of absorbent and refrigerant from said refrigerant absorber and return absorbent from said regenerator to said refrigerant absorber, said regenerator fluidly communicating with said boiler to receive steam from said boiler as a heat input; and

a pump for pumping the solution of absorbent and refrigerant from said refrigerant absorber to said regenerator.

2. The liquid desiccant air conditioner recited in claim 1, further comprising a heat exchanger fluidly communicating with said desiccant absorber, said condenser and said boiler, said heat exchanger operable to transfer heat from the concentrated liquid desiccant directed to said heat exchanger from said boiler to the dilute liquid desiccant directed to said heat exchanger from said desiccant absorber, and to deliver preheated dilute liquid desiccant to said condenser, wherein said condenser further preheats said dilute liquid desiccant prior to delivery to said boiler.

3. The liquid desiccant air conditioner recited in claim 1, further comprising a heat exchanger fluidly communicating with said condenser, said boiler and said desiccant absorber, said heat exchanger operable to transfer heat from concentrated liquid desiccant directed to said heat exchanger from said boiler to the preheated dilute liquid desiccant directed to said heat exchanger from said condenser to further preheat the dilute liquid desiccant prior to delivery to said boiler, said heat exchanger being disposed with respect to said boiler to recover waste heat from said boiler.

4. The liquid desiccant air conditioner recited in claim 1, wherein said desiccant absorber includes a top and a bottom and comprises: a plurality of horizontally and vertically disposed interconnected microglass fiber plates; a distributor disposed above said fiber plates at said top of said desiccant absorber for introducing the concentrated desiccant into said desiccant absorber; and a drain pan for collecting the dilute desiccant disposed at said bottom of said desiccant absorber.

5. The liquid desiccant air conditioner recited in claim 1, wherein said desiccant absorber includes a plurality of absorber pads bonded together and disposed side-by-side, said desiccant absorber further comprising a top distributor pan for distributing liquid desiccant to a top side of said pads, and a drain pan for collecting dilute liquid desiccant from a bottom side of said pads.

6. The liquid desiccant air conditioner recited in claim 1, wherein said boiler includes an inner vessel and an outer vessel, a heating element disposed in said inner vessel, and a pipe communicating heated liquid desiccant from said inner vessel and disposed within said outer vessel, whereby liquid desiccant is returned to said outer vessel from said condenser and is heated in said outer vessel by hot liquid desiccant passing through said pipe prior to entering said inner vessel.

7. The liquid desiccant air conditioner recited in claim 2, wherein said heat exchanger comprises at least one tube assembly including an inner tube concentrically disposed within an outer tube to define an annulus therebetween.

8. The liquid desiccant air conditioner recited in claim 7, wherein dilute liquid desiccant from said desiccant absorber is passed through said inner tube, and concentrated liquid desiccant is passed through said annulus.

9. The liquid desiccant air conditioner recited in claim 7, wherein dilute liquid desiccant from said desiccant absorber is passed through said annulus, and concentrated liquid desiccant is passed through said inner tube.

10. The liquid desiccant air conditioner recited in claim 7, wherein said inner tube is fabricated from Teflon, and said outer tube is fabricated from silicone rubber.

11. The liquid desiccant air conditioner recited in claim 2, wherein said heat exchanger comprises at least one tube assembly including an inner tube fabricated from Teflon concentrically disposed within an outer tube fabricated from silicone rubber to define an annulus therebetween.

12. The liquid desiccant air conditioner recited in claim 3, wherein said heat exchanger comprises at least one tube assembly including an inner tube concentrically disposed within an outer tube to define an annulus therebetween, said at least one tube assembly being coiled around said boiler to recover said waste heat.

13. The liquid desiccant air conditioner recited in claim 12, wherein dilute liquid desiccant from said condenser is passed through said inner tube, and concentrated liquid desiccant from said boiler is passed through said annulus.

14. The liquid desiccant air conditioner recited in claim 12, wherein dilute liquid desiccant from said condenser is passed through said annulus, and concentrated liquid desiccant from said boiler is passed through said inner tube.

15. The liquid desiccant air conditioner recited in claim 12, wherein said inner tube is fabricated from Teflon, and said outer tube is fabricated from silicone rubber.

16. The liquid desiccant air conditioner recited in claim 3, wherein said heat exchanger comprises at least one tube assembly including an inner tube fabricated from Teflon concentrically disposed within an outer tube fabricated from silicone rubber to define an annulus therebetween.

17. The liquid desiccant air conditioner recited in claim 1, wherein said condenser comprises an inner shell disposed within an outer housing defining at least one chamber between said inner shell and said housing.

18. The liquid desiccant air conditioner recited in claim 17, wherein said inner shell is fabricated from materials selected from the group of inconel, monel, titanium, Teflon, Teflon-coated copper, Teflon-coated aluminum, and Teflon-coated stainless steel; and said outer shell is fabricated from materials selected from the group of Teflon, polycarbonate, polyvinylidene fluoride, polypropylene, silicone rubber, polyethylene, and polystyrene.

19. The liquid desiccant air conditioner recited in claim 17, wherein said condenser further comprises at least one steam inlet communicating steam from said boiler with said at least one chamber and at least one solution inlet communicating dilute liquid desiccant with said inner shell.

20. The liquid desiccant air conditioner recited in claim 17, wherein said condenser further comprises at least one steam inlet communicating steam from said boiler with said inner shell and at least one solution inlet communicating dilute liquid desiccant with said at least one chamber.

21. The liquid desiccant air conditioner recited in claim 1, wherein said condenser comprises a housing and a plurality of tubes, said tubes being supported by opposing support plates, said tubes communicating with a steam inlet to receive steam from said boiler, said housing including a solution inlet to receive dilute liquid desiccant.

22. The liquid desiccant air conditioner recited in claim 21, wherein said tubes are at least one of convoluted and corrugated.

23. The liquid desiccant air conditioner recited in claim 21, wherein said tubes are fabricated from Teflon, and said support plates include at least one silicone rubber sheet attached thereto.

24. The liquid desiccant air conditioner recited in claim 17, wherein said inner shell divides said housing into two separate compartments, each compartment having a steam inlet and a condensate outlet, said housing further comprising a plurality of baffles to prevent short circuiting from said steam inlets to said condensate outlets.

25. The liquid desiccant air conditioner recited in claim 1, wherein said condenser comprises at least one tube assembly including an inner tube defining a first flow passageway and an outer tube, said inner tube being disposed within said outer tube to define an annular second flow passageway therebetween, wherein liquid desiccant is communicated through a first of said flow passageways and steam is communicated through a second of said flow passageways.

26. The liquid desiccant air conditioner recited in claim 25, wherein said inner tube is at least one of convoluted and corrugated.

27. The liquid desiccant air conditioner recited in claim 25, wherein said tube assembly is coiled.

28. The liquid desiccant air conditioner recited in claim 1, further comprising a frame fabricated from materials selected from the group of polypropylene, polyethylene, Teflon, polyvinylidene fluoride, polycarbonate, PVC and polystyrene.

29. The liquid desiccant air conditioner recited in claim 1, wherein said liquid desiccant is selected from the group of aqueous LiCl, LiBr and $CaCl_2$.

30. The liquid desiccant air conditioner recited in claim 29, wherein said liquid desiccant is a mixture of at least two of aqueous LiCl, LiBr and $CaCl_2$.

31. The liquid desiccant air conditioner recited in claim 1, wherein said boiler includes a vessel fabricated from plastic.

32. The liquid desiccant air conditioner recited in claim 31, wherein said plastic is selected from the group of Teflon, polycarbonate, fiber glass and polyvinylidene fluoride.

33. The liquid desiccant air conditioner recited in claim 1, further comprising means for pumping concentrated liquid desiccant into said desiccant absorber.

34. The liquid desiccant air conditioner recited in claim 1, further comprising an indirect evaporative cooler for cooling the incoming ambient air with exhaust air prior to passing the incoming air through said desiccant absorber.

35. The liquid desiccant air conditioner recited in claim 1, further comprising a direct evaporative cooler for further cooling the air cooled by said evaporator.

36. The liquid desiccant air conditioner recited in claim 34, further comprising a direct evaporative cooler for further cooling the air cooled by said evaporator.

37. The liquid desiccant air conditioner recited in claim 1, further comprising an indirect evaporative cooler for cooling dehumidified air from said desiccant absorber with exhaust air prior to passing the dehumidified air through said evaporator.

38. A liquid desiccant air conditioner, comprising:

a liquid desiccant absorber for absorbing moisture contained in ambient air entering the dehumidifier and passing through said desiccant absorber, said desiccant absorber constructed and arranged for receiving concentrated liquid desiccant and dispensing dilute liquid desiccant;

a boiler for boiling partially preheated dilute liquid desiccant to evaporate moisture to reconstitute the liquid desiccant into concentrated liquid desiccant;

a condenser fluidly communicating with said boiler to receive steam generated by boiling liquid desiccant in said boiler, said condenser further fluidly communicating with said absorber to receive dilute liquid desiccant from said absorber, said condenser being operable to sensibly heat the dilute liquid desiccant therein by recovering the latent heat of condensation as steam delivered from said boiler is condensed, to preheat said dilute liquid desiccant prior to delivery to said boiler;

an indirect evaporative cooler for cooling the incoming ambient air with exhaust air prior to passing the incoming air through said desiccant absorber; and

a direct evaporative cooler for further cooling the exiting said desiccant absorber.

39. A liquid desiccant air conditioner, comprising:

a liquid desiccant absorber for absorbing moisture contained in ambient air entering the dehumidifier and passing through said desiccant absorber, said desiccant absorber constructed and arranged for receiving concentrated liquid desiccant and dispensing dilute liquid desiccant;

a boiler for boiling partially preheated dilute liquid desiccant to evaporate moisture to reconstitute the liquid desiccant into concentrated liquid desiccant;

a condenser fluidly communicating with said boiler to receive steam generated by boiling liquid desiccant in said boiler, said condenser further fluidly communicating with said absorber to receive dilute liquid desiccant from said absorber, said condenser being operable to sensibly heat the dilute liquid desiccant therein by recovering the latent heat of condensation as steam delivered from said boiler is condensed, to preheat said dilute liquid desiccant prior to delivery to said boiler;

an indirect evaporative cooler for cooling air from said desiccant absorber with exhaust air; and

a direct evaporative cooler for further cooling air exiting said indirect evaporative cooler.

40. A liquid desiccant air conditioner, comprising:

a liquid desiccant absorber for absorbing moisture contained in ambient air entering the dehumidifier and passing through said desiccant absorber, said desiccant absorber constructed and arranged for receiving concentrated liquid desiccant and dispensing dilute liquid desiccant,

a boiler for boiling partially preheated dilute liquid desiccant to evaporate moisture to reconstitute the liquid desiccant into concentrated liquid desiccant; a first heat exchanger operable to transfer heat from the concentrated liquid desiccant to the dilute liquid desiccant directed to said first heat exchanger from said desiccant absorber to raise the temperature of the dilute liquid desiccant to a first temperature;

a first condenser fluidly communicating with said boiler to receive steam generated by boiling liquid desiccant in said boiler, said first condenser further fluidly communicating with said first heat exchanger to receive partially heated dilute liquid desiccant from said first heat exchanger at said first temperature, said first condenser being operable to sensibly heat the dilute liquid desiccant therein to a second temperature by recovering the latent heat of condensation as steam delivered from said boiler is condensed;

a second heat exchanger fluidly communicating with said first condenser, said boiler and said first heat exchanger, said second heat exchanger operable to transfer heat from concentrated liquid desiccant directed to said second heat exchanger from said boiler to the dilute liquid desiccant directed to said second heat exchanger from said first condenser at said second temperature to raise the temperature of the dilute liquid desiccant to a third temperature, said dilute liquid desiccant at the third temperature being directed to said boiler and said concentrated liquid desiccant being directed to said first heat exchanger, said second heat exchanger being disposed with respect to said boiler to recover waste heat from said boiler; and

a pump for pumping concentrated liquid desiccant into said absorber;

a second condenser;

an evaporator through which a refrigerant is passed to effect cooling of dehumidified ambient air from said desiccant absorber passing through said evaporator;

an expansion valve disposed between said condenser and said evaporator;

a refrigerant absorber fluidly communicating with said evaporator to receive vaporized refrigerant from said evaporator, said refrigerant absorber containing an absorbent for absorbing the vaporized refrigerant;

a regenerator for separating refrigerant from the absorbent, said regenerator fluidly communicating with said second condenser to supply separated refrigerant to said second condenser, said regenerator fluidly communicating with said refrigerant absorber to receive a solution of absorbent and refrigerant from said refrigerant absorber and return absorbent from said regenerator to said refrigerant absorber, said regenerator fluidly communicating with said boiler to receive steam from said boiler as a heat input; and

a pump for pumping the solution of absorbent and refrigerant from said refrigerant absorber to said regenerator.

41. The liquid desiccant air conditioner recited in claim 25, further comprising an air vent.

42. The liquid desiccant air conditioner recited in claim 41, wherein said air vent comprises Teflon tape.

43. The liquid desiccant air conditioner recited in claim 41, wherein said air vent is a float-type air vent.

44. The liquid desiccant air conditioner recited in claim 1, wherein a fraction of the liquid desiccant leaving said first condenser is recirculated to said liquid desiccant absorber.

45. The liquid desiccant air conditioner recited in claim 34, wherein at least a fraction of water supplied to said indirect evaporative cooler is obtained from condensate produced in at least one of said first condenser and said regenerator.

46. The liquid desiccant air conditioner recited in claim 35, wherein at least a fraction of water supplied to said direct evaporative cooler is obtained from condensate produced in at least one of said first condenser and said regenerator.

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