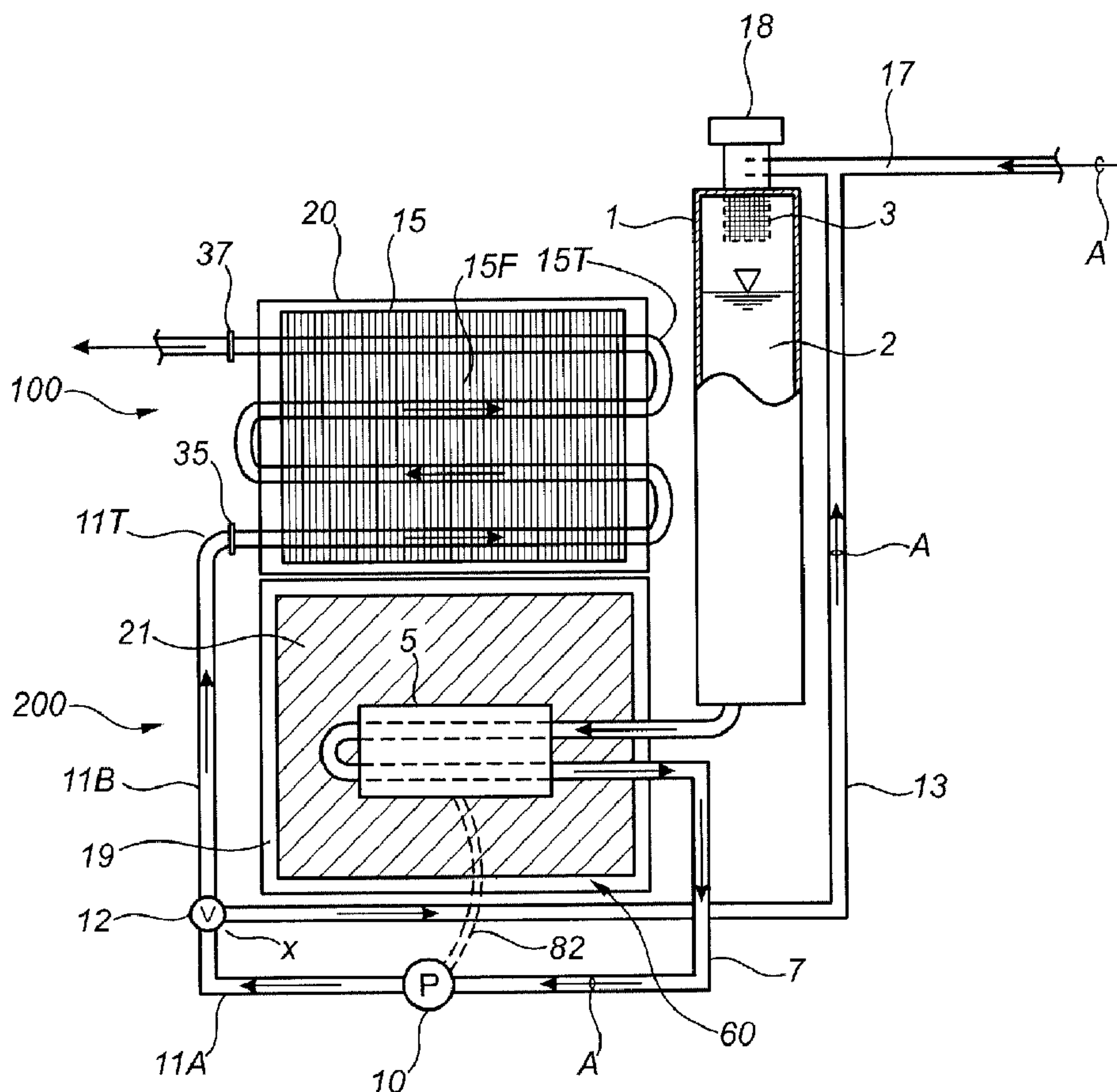




(22) **Date de dépôt/Filing Date:** 2008/12/17
 (41) **Mise à la disp. pub./Open to Public Insp.:** 2009/06/18
 (45) **Date de délivrance/Issue Date:** 2016/03/22
 (30) **Priorités/Priorities:** 2007/12/18 (US61/014,628);
 2008/08/07 (US61/086,865)

(51) **Cl.Int./Int.Cl.** *H01L 35/02* (2006.01),
E21B 36/00 (2006.01), *F23D 14/18* (2006.01),
F24H 1/10 (2006.01), *F24J 3/00* (2006.01)
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(54) **Titre : DISPOSITIF ECHANGEUR DE CHALEUR AVEC SYSTEME DE POMPAGE THERMIQUE**
 (54) **Title: HEAT TRACING APPARATUS WITH HEAT-DRIVEN PUMPING SYSTEM**



(57) **Abrégé/Abstract:**

In a heat tracing system using heat from a radiant heater to heat a circulating fluid, thermoelectric generation modules are used to generate electricity for powering a circulating pump. Thermoelectric power generation modules are sandwiched between a heat-

(57) Abrégé(suite)/Abstract(continued):

absorbing plate and a heat sink, and this assembly is positioned with the heat-absorbing plate adjacent to a radiant heater. A conduit loop passes through the heat sink, such that a fluid circulating through the conduit is heated from heat drawn from the heater into the heat sink. Due to the temperature differential between the hot and cold sides of the thermoelectric modules, the modules produce electricity to power the pump circulating the fluid through the conduit loop. Supplementary heat exchanger components may be provided for additional fluid-heating capacity, and thereby increasing the amount of heat available for the heat tracing loop.

ABSTRACT OF THE DISCLOSURE

In a heat tracing system using heat from a radiant heater to heat a circulating fluid, thermoelectric generation modules are used to generate electricity for powering a circulating pump. Thermoelectric power generation modules are sandwiched between a heat-absorbing plate and a heat sink, and this assembly is positioned with the heat-absorbing plate adjacent to a radiant heater. A conduit loop passes through the heat sink, such that a fluid circulating through the conduit is heated from heat drawn from the heater into the heat sink. Due to the temperature differential between the hot and cold sides of the thermoelectric modules, the modules produce electricity to power the pump circulating the fluid through the conduit loop. Supplementary heat exchanger components may be provided for additional fluid-heating capacity, and thereby increasing the amount of heat available for the heat tracing loop.

HEAT TRACING APPARATUS WITH HEAT-DRIVEN PUMPING SYSTEM

FIELD OF THE INVENTION

5 The present invention relates in general to systems for heating and circulating a fluid, and in particular to such systems that use catalytic heaters both to heat the fluid and to power a pump for circulating the fluid through a conduit loop, such as for heat tracing.

BACKGROUND OF THE INVENTION

10 It is well known to use heat from a catalytic heater (such as a Cata-Dyne™ heater, manufactured by CCI Thermal Technologies Inc. of Edmonton, Alberta, Canada) to heat a reservoir of fluid (such as glycol) for circulation through a heat tracing loop, for purposes such as thawing or preventing freezing of wellheads in cold climates. Examples of such applications can be found in U.S. Patents No. 6,776,227 (Beida et al.), No. 7,138,093 (McKay et al.), and No. 7,293,606 (Benoit et al.). These systems require a
15 pump to circulate the heated fluid through the heat tracing loop. However, since the heat tracing systems are commonly installed in remote locations (e.g., wellsites in northern Canada), the use of electrically-driven pumps is often not a practical option since the nearest electrical grid may be very far away. Solar power is not an ideal solution to this problem, because the pumps need to be operated extensively if not continuously during
20 very cold conditions, and the available sunlight may be minimal during such periods (especially in the far north). Accordingly, the use of electric pumps powered by solar panels typical entails the provision of substantial battery back-up for when the sun is not shining.

25 For the foregoing reasons, there is a need for more practical methods and systems for providing electrical power for electric pumps in conjunction with heat tracing systems using catalytic heaters. The present invention is directed to this need.

BRIEF SUMMARY OF THE INVENTION

In general terms, the present invention is a system and apparatus for heating a circulating fluid, using heat from a heater (such as a catalytic heater fuelled by natural gas or propane) both to heat the fluid and to generate electricity to power a pump for circulating the fluid through a conduit system (such as a heat tracing loop). In particular
5
embodiments, the system produces sufficient electricity to serve needs over and above the power requirements of the circulating pump.

In accordance with the present invention, electric power is generated thermoelectrically, using heat from a suitable heater, and preferably a catalytic heater.
10
The principles of thermoelectric power generation have been understood and applied for many years. It is known (in accordance with a scientific principle called the “Seebeck effect”) that electrical power can be produced in a thermocouple comprising “p-type” (i.e., positive) and “n-type” (i.e., negative) thermoelectric elements or modules which are connected electrically in series and thermally in parallel, by pumping heat from one side
15
 (the “hot side” or “hot junction”) of the thermocouple to the other side (the “cold side” or “cold junction”). This will generate an electrical current proportional to the temperature gradient across the thermocouple (i.e., between the hot and cold sides).

In the present invention, one or more thermoelectric generation modules (commonly referred to as “TEG modules”) are interposed or “sandwiched” between a
20
 heat-absorbing plate and a heat sink. For purposes of this patent document, any assembly of a heat-absorbing plate, one or more TEG modules, and a heat sink will be referred to as a “TEG board”. The TEG board is positioned with its heat-absorbing plate adjacent to (and preferably generally parallel to) a radiant heater, with an air space between the heat-absorbing plate and the heater. The sides of the TEG modules adjacent to the heat-absorbing plate will thus be the hot sides, and the other sides of the TEG modules (i.e.,
25
 adjacent to the heat sink) will be the cold sides. A conduit loop passes through the heat sink, such that a fluid circulating through the conduit will be heated from heat drawn from the heater into the heat sink. The fluid is circulated by an electric pump. Due to the temperature differential between the hot and cold sides of the TEG modules (enhanced by

the heat transfer from the heat sink into the circulating fluid), electrical power is produced by the TEG modules, for powering the pump, and for other applications depending on the total power output of the system.

5 Accordingly, in one embodiment the present invention is an apparatus for generating electrical power, said apparatus comprising a catalytic heater and a plurality of thermoelectric modules each having a hot side and a cold side, wherein the hot sides of the thermoelectric modules are exposed to heat from the catalytic heater, and the cold sides of the thermoelectric modules are in thermally-conductive proximity to a heat sink, such that the thermoelectric modules produce an electric current for powering a pump for
10 circulating heated fluid within a heat tracing conduit loop, and wherein the heat tracing conduit loop passes through the heat sink to dissipate heat therefrom.

In another embodiment, the invention is an apparatus for generating electrical power, in which the apparatus comprises a first heat-absorbing plate; a heat sink having a first side and a second side; and a first plurality of thermoelectric modules each having a
15 hot side and a cold side, said modules being electrically interconnected, and sandwiched between the heat-absorbing plate and the first side of the heat sink, with their hot sides adjacent the heat-absorbing plate. When the apparatus is positioned closely adjacent to a radiant heat source, with the first heat-absorbing plate nearest the heat source, heat from the radiant heat source will pass through the first heat-absorbing plate and the
20 thermoelectric modules and into the heat sink, thus activating the thermoelectric modules to produce electricity. Preferably, the heat sink comprises one or more blocks of heat-conducting material such as copper or aluminum, with each block having one or more channels to receive one or more fluid-carrying conduits.

In preferred embodiments, the apparatus includes:

- 5 (a) a collector tank having an inlet and an outlet, said collector tank being in fluid communication with the conduit loop, with the conduit loop's outlet section connected to the tank outlet of the tank, and with the conduit loop's return section connected to the tank inlet; and
- (b) a pump for circulating a fluid through the conduit loop, said pump being energized by electrical power produced by the first plurality of thermoelectric modules in response to the flow therethrough of heat from the first radiant heater.

10 The apparatus optionally may include a supplemental heat exchanger incorporated into the conduit loop such that fluid flowing through the conduit loop will flow through the supplemental heat exchanger, with the supplemental heat exchanger being positioned so as to be exposed to heat from the first radiant heater.

BRIEF DESCRIPTION OF THE DRAWINGS

15 Embodiments of the invention will now be described with reference to the accompanying figures, in which numerical references denote like parts, and in which:

FIGURE 1 is cross-section through a TEG board assembly mounted in association with a catalytic heater in accordance with a first embodiment of the present invention.

20 **FIGURE 2** is an exploded elevation of the TEG board shown in Fig. 1.

FIGURE 3 is a schematic elevation of a heat tracing system in accordance with a first embodiment of the present invention, incorporating a TEG board assembly as shown in Figs. 1 and 2.

25 **FIGURE 4** is a schematic elevation of a heat tracing system in accordance with a second embodiment of the invention.

FIGURE 5 is a cross-section through a heat tracing system in accordance with a third embodiment of the present invention.

FIGURE 6 is an exploded elevation of a TEG board arrangement as in Figs. 4 and 5, illustrating an exemplary TEG module layout.

5 **FIGURE 7** is a schematic layout of a heat tracing system incorporating “master” and “slave” embodiments of the present invention.

10 **FIGURE 8** schematically illustrates electrical circuitry for simultaneously charging a storage battery and energizing a fluid circulation pump using power generated by apparatus in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

15 Figs. 1, 2, and 3 illustrate one embodiment of the “TEG board” assembly **60** of a thermoelectric generation apparatus in accordance with the present invention. As schematically illustrated in Fig. 1, a cluster of TEG modules **8** are sandwiched between a heat-absorbing plate **21** (adjacent the hot sides **8H** of modules **8**) and a heat sink **5** (adjacent the cold sides **8C** of modules **8**). Each TEG module **8** has a positive lead wire **80P** and a negative lead wire **80N**. Although no corresponding electrical connection details are shown in the Figures, the lead wires **80P** and **80N** from the clustered TEG modules **8** are electrically connected as appropriate, in accordance with known principles and techniques, such that all electrical power developed by the TEG module cluster is available through power outlet cables **82** leading out from TEG board **60**.as schematically illustrated in Fig. 3. Fig. 2 illustrates one possible configuration of the cluster of modules **8** (and here it is to be noted that the present invention is not dependent on the use of any particular number or arrangement of TEG modules **8**).

25 TEG board assembly **60** is positioned with heat-absorbing plate **21** in close proximity to the heat-radiating face **19H** of a first catalytic heater **19**, thus initiating the thermoelectric process to generate an electrical current which can be used to power an electric pump to circulate heated fluid through a heat tracing loop. Preferably, an air

space **23** will be provided between heat-absorbing plate **21** and first catalytic heater **19**. Heat-absorbing plate **21** should be as close as possible to heater **19** to maximize heat transfer to plate **21**, but not so close as to interfere with the availability of oxygen for proper catalytic reaction in heater **19**. The width of air space **23** is variable to suit the size
5 of heat-absorbing plate **21** and other design particulars for specific applications.

Brackets or other suitable connectors (as schematically represented by reference numeral **30**) may be used to mount heat sink **5** to plate **21**, and to mount plate **21** to heater **19**. Connectors **30** preferably will be designed and located to minimize any obstruction of vertical air flow through air space **23**. In preferred embodiments, a heat exchanger
10 face plate (not shown) is provided to cover heat exchanger **15** in order to minimize heat loss from heat exchanger **15** and thus maximize heat transfer to the fluid flowing through tubing **15T**. For similar purposes, a suitable cover plate or enclosure (preferably insulated), may optionally be provided to enclose TEG board assembly **60**.

In accordance with previously-stated principles, the current intensity will vary
15 according to the total amount of heat passing from the hot side to the cold side of the TEG module cluster. Therefore, in order to maximize the current generated by a given number of TEG modules, it is desirable to maximize the temperature of the heat source to which the hot sides of the modules are exposed, and to minimize the temperature on the cold side – in other words, to maximize the temperature gradient.

20 The temperature at the face of a given catalytic heater will be essentially fixed, so increasing the temperature of the heat source will typically not be an option. However, the heat sink **5** has the effect of minimizing the cold-side temperature by absorbing or dissipating heat from the cold sides of the modules **8**. The effectiveness of a heat sink varies according to the properties of the material used (specifically, its heat-conducting
25 capacity) and the mass of the heat sink. In the preferred embodiment of the present invention, heat sink **5** is provided, preferably in the form of a thick block of a material that has a high coefficient of heat conductivity (for example, aluminum, copper, or other heat-conductive metal, or a heat-conductive non-metallic or sub-metallic composite material). In embodiments using an aluminum heat sink **5**, the aluminum is preferably

anodized (for greater service life) and painted black or some other dark colour (for enhanced heat absorption). In accordance with a particularly preferred embodiment, the effectiveness of heat sink **5** is enhanced by providing liquid cooling, in the form of fluid conduits **52** passing through channels **50** in heat sink **5**. Heat will thus be transferred from heat sink **5** to, and carried away by, the fluid flowing in conduits **52**, thus lowering the temperature of heat sink **5**. In alternative embodiments, suitable fittings may be fitted to the ends of channels **50**, to facilitate connection to conduits **52**, such that conduits **52** do not actually pass through channels **50**.

Fig. 3 illustrates an example of how the catalytic heat-driven thermoelectric power generation system of the present invention can be integrated with a conventional heat tracing system that uses a catalytic heater to heat the circulating heat tracing fluid. The upper section of the illustrated apparatus is a heat tracing section **100** comprising a fluid collector tank **1** which contains a fluid **2** (such as glycol). Collector tank **1** has a filler cap **18**, and preferably also has a fine screen **3** to prevent particulate contaminants from entering collector tank **1**. A heat exchanger **15** of suitable design is also provided, and in the illustrated embodiment is a finned-tube heat exchanger of well-known type, comprising tubing **15T** (such as copper tubing) sinuously routed through an assembly of fins **15F** (preferably painted black to maximize heat absorption). Tubing **15T** has an inlet end **35** and an outlet end **37**. A second catalytic heater **20** is positioned directly adjacent to heat exchanger **15** so that heat from second catalytic heater **20** will be transferred to fins **15F** of heat exchanger **15** and thence to a fluid circulating through tubing **15T** of heat exchanger **15**. A loop of heat tracing conduit is also provided, with an outlet section **16** connected to the outlet end of tubing **15T**, and a return section **17** connected to an upper region of collector tank **1** (preferably in association with filler cap **18** at a point above screen **3**, as shown in Fig. 3). A heat exchanger face plate (not shown) is preferably provided to cover heat exchanger **15** in order to minimize heat loss from heat exchanger **15** and thus maximize heat transfer to the fluid flowing through tubing **15T**.

In a conventional heat tracing apparatus of this sort, a further length of conduit or piping would extend from a lower region of collector tank **1** to a circulation pump and from the pump to the inlet end of the copper tubing of heat exchanger **15**, thus completing

the closed fluid conduit loop. In accordance with the present invention, however, heat tracing section **100** is coupled with thermoelectric generation apparatus **200** by running a fluid conduit from a lower region of collector tank **1** through heat sink **5** (through conduit section **52** in Fig. 3), then looping back through heat sink **5** (through conduit section **7**) to an electric pump **10** (such as a vane pump), and thence, through conduit section **11**, to inlet end **35** of tubing **15T** of heat exchanger **15**. The TEG module cluster of thermoelectric generation apparatus **200** is electrically connected to pump **10** by way of power outlet cables **82**, such that actuation of first catalytic heater **19** will cause the generation of an electric current to power pump **10**. Actuation of second catalytic heater **20** will cause heat tracing fluid **2** flowing through tubing **15T** to be heated, whereupon it may be conveyed (by pump **10**) through heat tracing outlet line **16** to a wellhead or other item needing heat. Heat tracing fluid **2** flows through return line **17** to collector tank **1** and thence through heat sink **5**. Having lost heat to the wellhead or other heated item, the fluid **2** passing through heat sink **5** has significant capacity to absorb heat from heat sink **5**; in this way, circulation of fluid **2** through heat sink **5** effectively preheats fluid **2** before it reaches heat exchanger **15**.

The apparatus of the present invention preferably incorporates a by-pass conduit **13** to facilitate start-up of the system. As shown in Fig. 3, by-pass conduit **13** extends between return line **17** (preferably at a point close to collector tank **1**) and a point **X** along conduit section **11** between pump **10** and inlet end **35** of tubing **15T** of heat exchanger **15** (thus subdividing conduit section **11** into subconduit **11A** between pump **10** and point **X**, and subconduit **11B** between point **X** and a terminal end **11T**, as shown in Fig. 3). A by-pass valve **12** is provided at point **X**. Valve **12** is operable between a normal position (in which fluid is free to flow from subconduit **11A** into subconduit **11B**) and a by-pass position (in which the flow of fluid from subconduit **11A** into subconduit **11B** is blocked, and is instead diverted into by-pass conduit **13**). This by-pass circuit makes it possible to circulate fluid through heat sink **5** without having to circulate the fluid through heat exchanger **15** and the full heat tracing conduit loop (i.e., outlet section **16** and return section **17**), which would require considerably more power.

Operation of the system may now be explained with reference to Fig. 3 and the foregoing description. To facilitate understanding of the system, Fig. 3 includes numerous arrows **A** indicating the flow direction of fluid **2** circulating through the sections of tubing and conduit in the system.

5 To start the system, the fuel supply (e.g., natural gas) to first and second catalytic heaters **19** and **20** is turned on, and first catalytic heater **19** is connected to battery power to initiate the catalytic reaction. By-pass valve **12** is then moved to the by-pass position. Once the catalytic reaction in first catalytic heater **19** is underway, heater **19** begins to direct infrared heat to heat-absorbing plate **21**, beginning the thermoelectric generation process in TEG modules **8**. In one tested experimental system, when the thermoelectrically-generated power reached a voltage of about 0.7 volts, pump **10** began to turn slowly, and started moving fluid through the by-pass circuit and through heat sink **5**. The voltage spiked instantly as fluid started passing through heat sink **5**. First catalytic heater **19** may then be disconnected from battery power. Second catalytic heater 10
15 **20** may then be actuated by connecting it to battery power (which may be disconnected after the catalytic reaction in second catalytic heater **20** is well established).

When the voltage reaches a high enough level (about 5 volts in tested systems), by-pass valve **12** may be moved to the normal position, thus allowing fluid to circulate through the complete system. The thermoelectric generation apparatus will continually increase the voltage being supplied to pump **10** until it reaches a stabilized level (in approximately 30 minutes in tested systems). The system may be shut down by simply turning off the gas supply. As the heat being generated by first catalytic heater **19** dissipates, the electrical power being supplied to pump **10** will decrease until pump **10** quits. 20

25 The advantages of the present system will be readily appreciated by persons skilled in the art of the invention. The primary benefit is that so long as there is fuel for the catalytic heaters, there will be continuous electrical power to actuate the circulation pump. This eliminates the need for an external electrical power supply, and eliminates one of the main drawbacks of using solar power (e.g., intermittent or sporadic power

generation; need for substantial storage battery back-up). The required battery power for the system is only what is needed to initiate the catalytic reactions in the catalytic heater (or heaters).

Fig. 4 illustrates an alternative embodiment that uses a single catalytic heater **19** to heat the circulating fluid and generate electrical power. In the primary configuration of this embodiment, fluid **2** is heated as it passes through conduits **52** and a pair of heat sinks **5**. As shown in Fig. 4, however, supplemental heat exchanger means **70** (such as a finned tube section, as illustrated in Fig. 4) may optionally be mounted above catalytic heater **19** for enhanced fluid heating, with supplemental heat exchanger **70** (of any suitable type) incorporated into the main fluid conduit loop. Preferably, supplemental heat exchanger **70** is enclosed within an exhaust vent hood (not shown in Fig. 4) to maximize the amount of residual heat to which supplemental heat exchanger **70** is exposed. In embodiments incorporating supplemental heat exchanger **70**, a secondary valve **72** is preferably provided at terminal end **11T**, with secondary valve **72** being operable between a first position allowing fluid **2** to circulate through supplemental heat exchanger **70** and thence into conduit outlet section **16**, and a second position allowing fluid **2** to by-pass supplemental heat exchanger **70** and flow directly into conduit outlet section **16**.

The embodiment shown in Fig. 4 uses a pair of elongate heat sinks **5**, to increase the system's fluid-heating capacity and to facilitate the use of a larger number of TEG modules, thus increasing the system's power-generating capacity. In this heat sink arrangement, conduit **52** loops through both heat sinks **5**. Persons skilled in the art of the invention will readily appreciate that one or more additional heat sinks could be incorporated into this or other alternative embodiments of the system without departing from the scope and principles of the present invention.

Fig. 5 illustrates a variant of the embodiment shown in Fig. 4 which uses a pair of catalytic heaters **19** mounted on either side of a modified or "double" TEG board assembly having two electrically-independent TEG module circuits. As shown in Fig. 5, the heat sink **5** or sinks (two heat sinks **5** being provided in the particular embodiment of

Fig. 5) are sandwiched between a pair of heat-absorbing plates **21**, with a cluster of TEG modules **8** provided on each side of each heat sink **5** so as to be sandwiched between the corresponding heat sink **5** and heat-absorbing plate **21**. Brackets **30** and cross-ties **32** are shown in Fig. 5 to illustrate means for mounting heater **19** to the double TEG board assembly and for interconnecting the two heat-absorbing plates **21**. Persons skilled in the art will appreciate, however, that these depictions are conceptual only, and that the present invention is in no way restricted to the use of any particular type of mounting or connection means.

As will be immediately apparent, this embodiment doubles the amount of heat available for heating the circulating fluid **2** and for electrical power generation, without increasing the number of heat sinks **5** required. Of course, it may be necessary or desirable to modify the size (and possibly the material properties) of heat sinks **5** in order to optimize the operational benefits of this arrangement, but it will generally be more efficient to use a given number of larger heat sinks **5** than a larger number of smaller heat sinks **5** having equivalent mass.

The use of two electrically-independent TEG module circuits facilitates use of the generated power for different purposes. For example, each TEG module circuit may have its own separate set of power outlet cables **82** (not shown in Fig. 5) such that the power output from one TEG module circuit may be dedicated to energizing fluid circulation pump **10**, with power from the other circuit being used for battery charging or other purposes. Alternatively, all of the TEG modules may be connected such that the full electrical output of the system is carried by a single set of power outlet cables **82**.

Fig. 5 illustrates supplemental heat exchanger elements **70** positioned above catalytic heaters **70**, but such supplemental heat exchanger elements **70** are optional and not essential. In embodiments both with and without supplemental heat exchanger elements **70**, an exhaust hood **80** is preferably provided above the heater / TEG board assembly as shown in Fig. 5. In embodiments having supplemental heat exchanger elements **70**, said heat exchanger elements **70** are preferably enclosed within exhaust hood **80** in order to maximize the heat exposure of heat exchanger elements **70**.

It will be readily appreciated that alternative embodiments of the present invention may use only a single heater **19** and only one TEG board assembly (rather than the double TEG board shown in Fig. 5), with or without supplemental heat exchanger elements **70**, and with or without exhaust hood **80**. One alternative embodiment uses an exhaust hood **80** that is configured to partially or completely house fluid collection tank **1**, which will thus be exposed to waste heat from heater **19** (and heater **20** in certain embodiments).

Fig. 6 illustrates a preferred TEG module arrangement for embodiments using a pair of elongate heat sinks **5** (such as shown in Figs. 4 and 5). As previously noted, however, the present invention is not restricted to any particular number or arrangement of TEG modules **8**, and persons skilled in the art will appreciate that many alternative TEG module arrangements are possible.

Although not specifically illustrated, a further embodiment using four catalytic heaters can be used in applications requiring greater fluid-heating and power-generating capabilities. This embodiment would essentially incorporate a system as in Fig. 5, with a “double” TEG board assembly disposed between a pair of lower catalytic heaters, plus a supplemental heater exchanger positioned above the double TEG board between a pair of upper catalytic heaters. In essence, this alternative embodiment would constitute a doubled-up version of the embodiment illustrated in Fig. 3.

Fig. 7 schematically illustrates one example of how multiple embodiments of the present invention can be incorporated into a heat tracing circuit or a building heating system. In the illustrated layout, a “master” unit **90** in accordance with a selected embodiment of the apparatus of the invention, and complete with a pump (not shown in Fig. 7) and an associated fluid collector tank **1**, is used for primary fluid-heating and power-generating purposes to circulate a heated fluid through a conduit system **93** to provide heat for a building **B** (or to circulate heated fluid through a heat tracing circuit to heat a well head or other installation). The illustrated building heating system also incorporates a “slave” unit **92**, which again may be in accordance with any selected embodiment of the invention, but does not require a pump or an associated fluid collector

tank. Slave unit **92** produces additional electrical power, and also serves as an effective heat exchanger to increase the temperature of the circulating fluid. Slave unit **92** may also (or alternatively) be used to provide primary or supplemental electrical power for charging one or more batteries (not shown), for use in start-up of master unit **90** or for
5 other desired purposes. In preferred embodiments, slave unit **92** will be generally as shown in Fig. 4 or Fig. 5, but not necessarily including supplemental heat exchanger **70**.

As shown in Fig. 7, fluid conduit system **93** provides heated fluid to suitable radiator elements **94** (such as hydronic finned baseboard heaters of known type) installed in building **B**. Direction arrows **A** indicate the direction of fluid flow through conduit
10 system **93** and radiators **94**. Additional heat may optionally be provided by one or more second stage heaters **95** incorporated into the conduit / radiator system. Second stage heater **95** may be of any suitable type, including a selected embodiment of the apparatus of the present invention (although power-generation capacity will not necessarily be required for second stage heater **95**), or a heat exchanger / catalytic heater combination
15 similar to upper section **100** of the apparatus shown in Fig. 3 (i.e., with no TEG board).

Fig. 8 schematically illustrates one possible system for using a TEG board assembly (in accordance with a selected embodiment of the apparatus of the present invention) to energize a fluid circulation pump while simultaneously charging a battery. Fig. 8 shows a TEG board assembly **60** with fluid conduit **7** running from TEG board **60**
20 to pump **10**, and with power outlet cables **82**. For clarity and simplicity, the catalytic heater **19** and other components associated with TEG board **60** are not shown in Fig. 8. Using parallel circuitry as shown in Fig. 8, power outlet cables **82** are connected to a DC (i.e., direct current) converter or charge controller **84**, while supplementary power cables **85** run from DC converter **84** to the terminals of a storage battery **86** (thus charging
25 battery **86**), and additional supplementary power cables **87** run from the terminals of battery **86** to energize fluid circulation pump **10**.

The various embodiments of the apparatus of the present invention preferably will incorporate a thermal safety switch associated with heat sink **5** and electrically connected to a switch operable to shut off the flow of fuel gas (e.g., natural gas or propane) to

heaters **19** and **20**. The thermal safety switch will include a temperature probe for sensing the temperature of heat sink **5**. Should the temperature of heat sink **5** rise above a predetermined temperature probe setting (due to failure of pump **10** or any other cause), the thermal safety switch will shut off the fuel gas supply. Persons skilled in the art of the invention will appreciate that various known technologies may be used or readily adapted to provide thermal safety shutdown means for use with the present invention.

It will also be readily appreciated by those skilled in the art that various modifications of the present invention may be devised without departing from the essential concept of the invention, and all such modifications are intended to come within the scope of the present invention and the claims appended hereto. It is to be especially understood that the invention is not intended to be limited to illustrated embodiments, and that the substitution of a variant of a claimed element or feature, without any substantial resultant change in the working of the invention, will not constitute a departure from the scope of the invention.

In this patent document, the word "comprising" is used in its non-limiting sense to mean that items following that word are included, but items not specifically mentioned are not excluded. A reference to an element by the indefinite article "a" does not exclude the possibility that more than one of the element is present, unless the context clearly requires that there be one and only one such element.

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THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A heat-tracing apparatus comprising:

- 5 (a) a first flameless catalytic heater having a generally flat heat-radiating face;
- (b) a first heat-absorbing plate having an inner face and a dark-coloured outer face, said outer face being positioned adjacent and substantially parallel to the heat-radiating face of the first catalytic heater with an intervening air space therebetween, such that the outer face of the first heat-absorbing plate will be
10 exposed to radiant heat from the first catalytic heater upon actuation thereof;
- (c) a first plurality of electrically interconnected thermoelectric modules each having a hot side and a cold side;
- (d) a heat sink comprising one or more blocks of a heat-conducting material and having a first side and a second side;
- 15 (e) a closed conduit loop passing through the heat sink; and
- (f) a pump for circulating a fluid through the conduit loop;

wherein:

- (g) the first plurality of thermoelectric modules are sandwiched between the inner face of the first heat-absorbing plate and the first side of the heat sink, with
20 their hot sides in thermally-conductive proximity to the inner face of the first heat-absorbing plate, and with their cold sides in thermally-conductive proximity to the first side of the heat sink, such that the first plurality of thermoelectric modules will produce an electric current when a fluid is introduced into the conduit loop and the first catalytic heater is actuated, with
25 the electric current thus produced being sufficient to power the pump; and
- (h) a fluid circulating through the conduit loop will be heated by heat drawn into the heat sink from the first catalytic heater.

2. The apparatus of Claim 1, wherein the heat-conducting material of at least one of the one or more blocks comprises a metal selected from the group consisting of copper and aluminum.

3. The apparatus of Claim 1 or Claim 2, further comprising:

- 5 (a) a second flameless catalytic heater having a generally flat heat-radiating face;
- (b) a second heat-absorbing plate having an inner face and a dark-coloured outer face, said outer face being positioned adjacent and substantially parallel to the heat-radiating face of the second catalytic heater with an intervening air space therebetween, such that the outer face of the second heat-absorbing plate will
10 be exposed to radiant heat from the second catalytic heater upon actuation thereof; and
- (c) a second plurality of electrically interconnected thermoelectric modules each having a hot side and a cold side;

wherein:

- 15 (d) the second plurality of thermoelectric modules are sandwiched between the inner face of the second heat-absorbing plate and the second side of the heat sink, with their hot sides in thermally-conductive proximity to the inner face of the second heat-absorbing plate, and with their cold sides in thermally-conductive proximity to the second side of the heat sink, such that the second
20 plurality of thermoelectric modules produce an electric current; and
- (e) a fluid circulating through the conduit loop will be further heated by heat drawn into the heat sink from the second catalytic heater.

4. The apparatus of Claim 1 or Claim 2, further comprising a finned-tube heat exchanger and a second flameless catalytic heater having a heat-radiating face, wherein:

- 25 (a) the conduit loop passes through the heat exchanger; and
- (b) the second catalytic heater is positioned with its heat-radiating face adjacent to the heat exchanger such that a fluid flowing through the heat exchanger will be heated by radiant heat from the second catalytic heater.

5. The apparatus of Claim 1 or Claim 2 wherein the conduit loop flows through a finned-tube heat exchanger positioned above the first catalytic heater such that a fluid flowing through the heat exchanger will be heated by waste heat from the first catalytic heater.
- 5 6. The apparatus of Claim 3 wherein the conduit loop flows through a finned-tube heat exchanger positioned above the first and second catalytic heaters such that a fluid flowing through the heat exchanger will be heated by waste heat from the first and second catalytic heaters.
7. The apparatus of any one of Claims 1-6, wherein:
- 10 (a) the conduit loop comprises an outlet section and a return section; and
- (b) a collector tank having an inlet and an outlet, said collector tank being in fluid communication with the conduit loop, with the conduit loop's outlet section connected to the tank outlet of the tank, and with the conduit loop's return section connected to the tank inlet.
- 15 8. The apparatus of any one of Claims 1-7 wherein the first catalytic heater is fuelled by a fuel gas selected from the group consisting of propane and natural gas.
9. The apparatus of any one of Claims 3, 4, and 6 wherein the second catalytic heater is fuelled by a fuel gas selected from the group consisting of propane and natural gas.
10. The apparatus of any one of Claims 4-6, further comprising a by-pass conduit and an associated by-pass valve, said by-pass valve being operable between a first position in which fluid is free to flow through the heat sink and thence through the heat exchanger, and a second position in which fluid will flow through the heat sink but not through the heat exchanger.
- 20

11. The apparatus of Claim 7, further comprising a by-pass conduit and an associated by-pass valve, said by-pass valve being operable between:

5 (a) a first position in which fluid will flow from the collector tank, through the heat sink, and thence through the conduit loop back to the collector tank, but will not flow through the by-pass conduit; and

(b) a second position in which fluid will flow from the collector tank, through the heat sink, and thence through the by-pass conduit back to the collector tank, but will not flow through the conduit loop from the heat sink back to the collector tank.

10 12. The apparatus of any one of Claims 1-11, further comprising a thermal safety switch associated with the heat sink, said safety switch being operable to shut off a flow of fuel gas to the first catalytic heater if the temperature of the heat sink exceeds a predetermined value.

13. The apparatus of Claim 12 wherein the thermal safety switch comprises a temperature probe for sensing the temperature of the heat sink.

15 14. The apparatus of Claim 1 wherein the pump is powered solely by electric current produced by the first plurality of thermoelectric modules.

15. The apparatus of Claim 3 wherein the pump is powered solely by electric current produced by the first and second pluralities of thermoelectric modules.

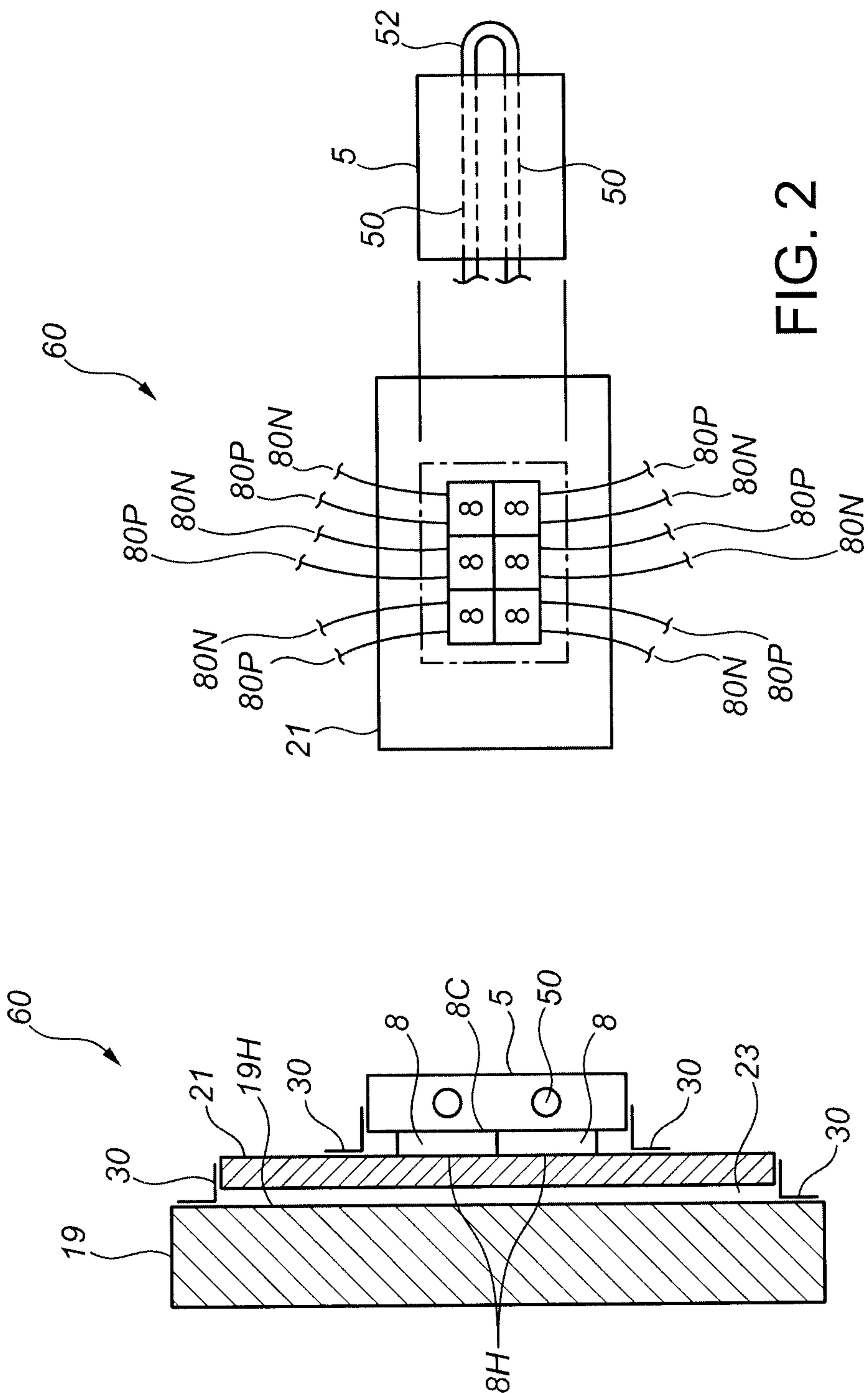


FIG. 1

FIG. 2

FIG. 3

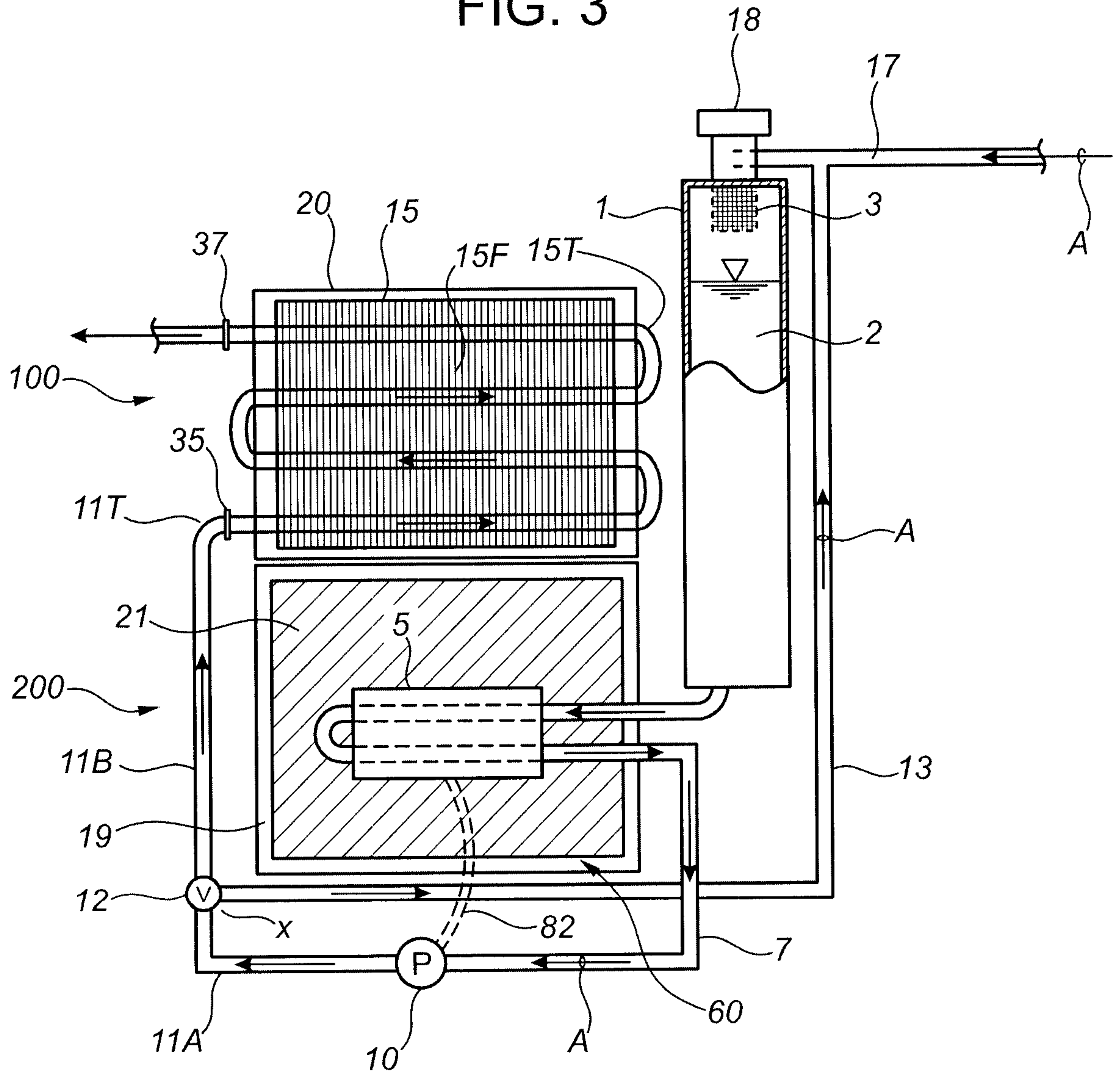
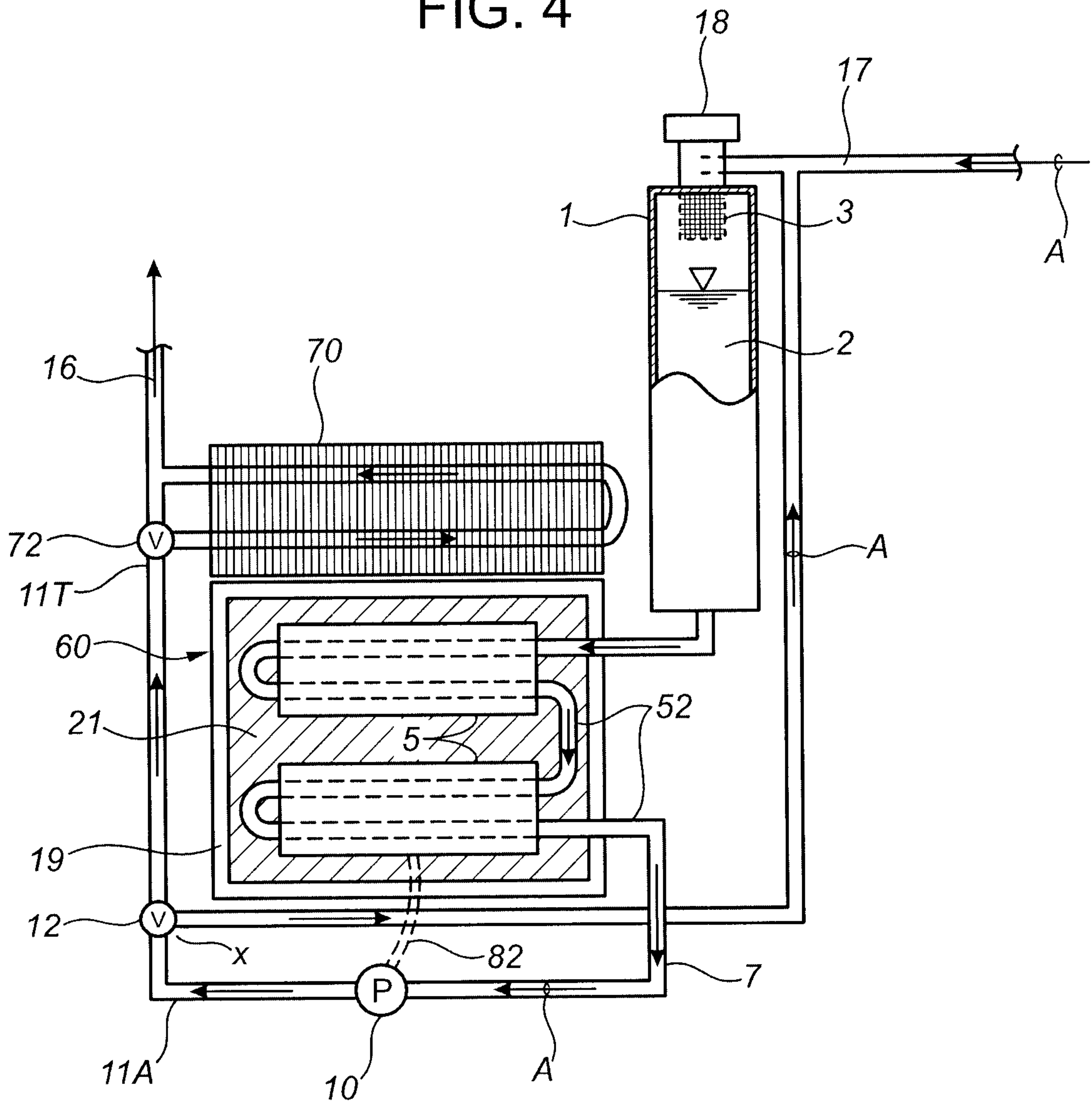


FIG. 4



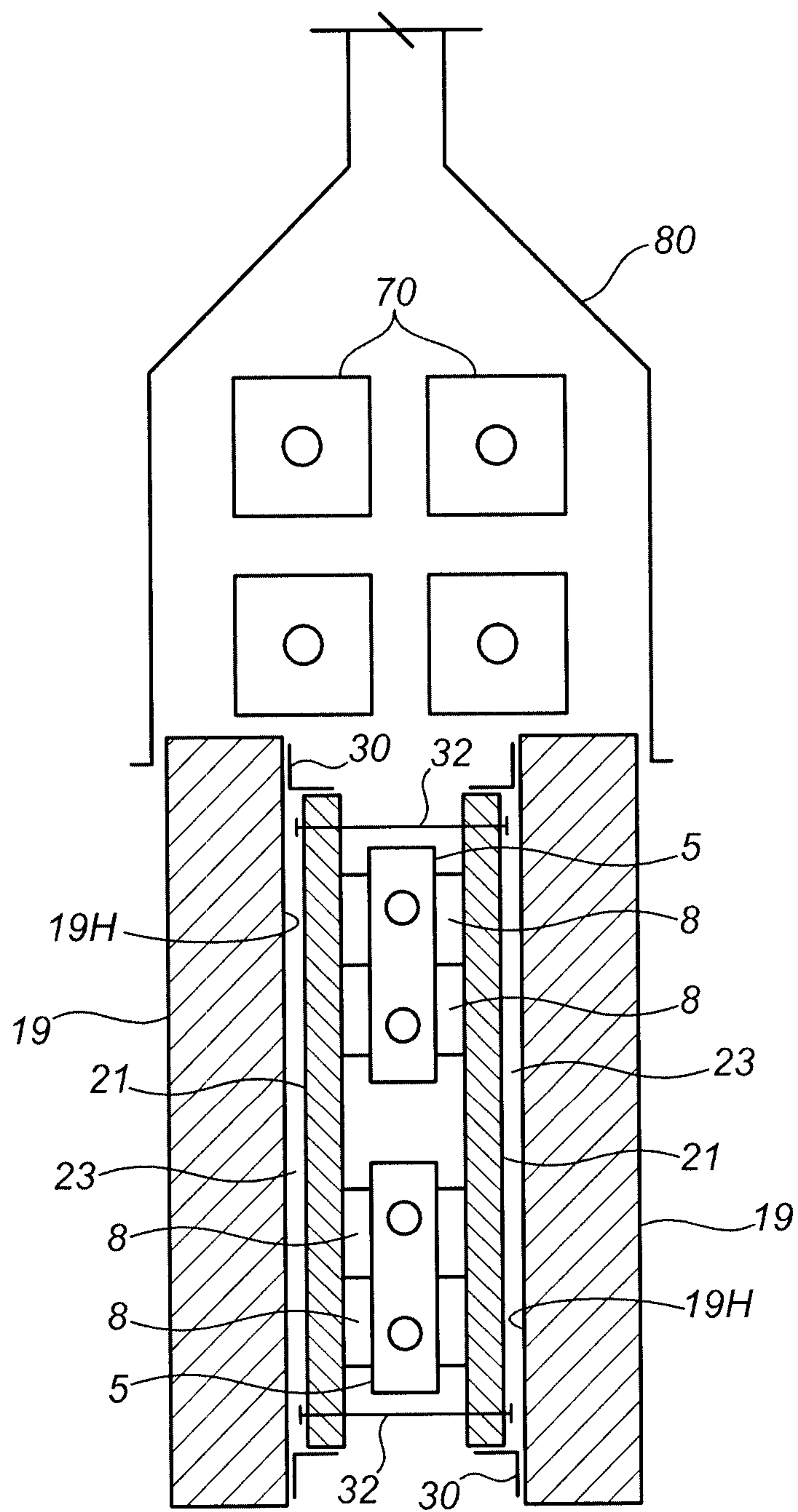
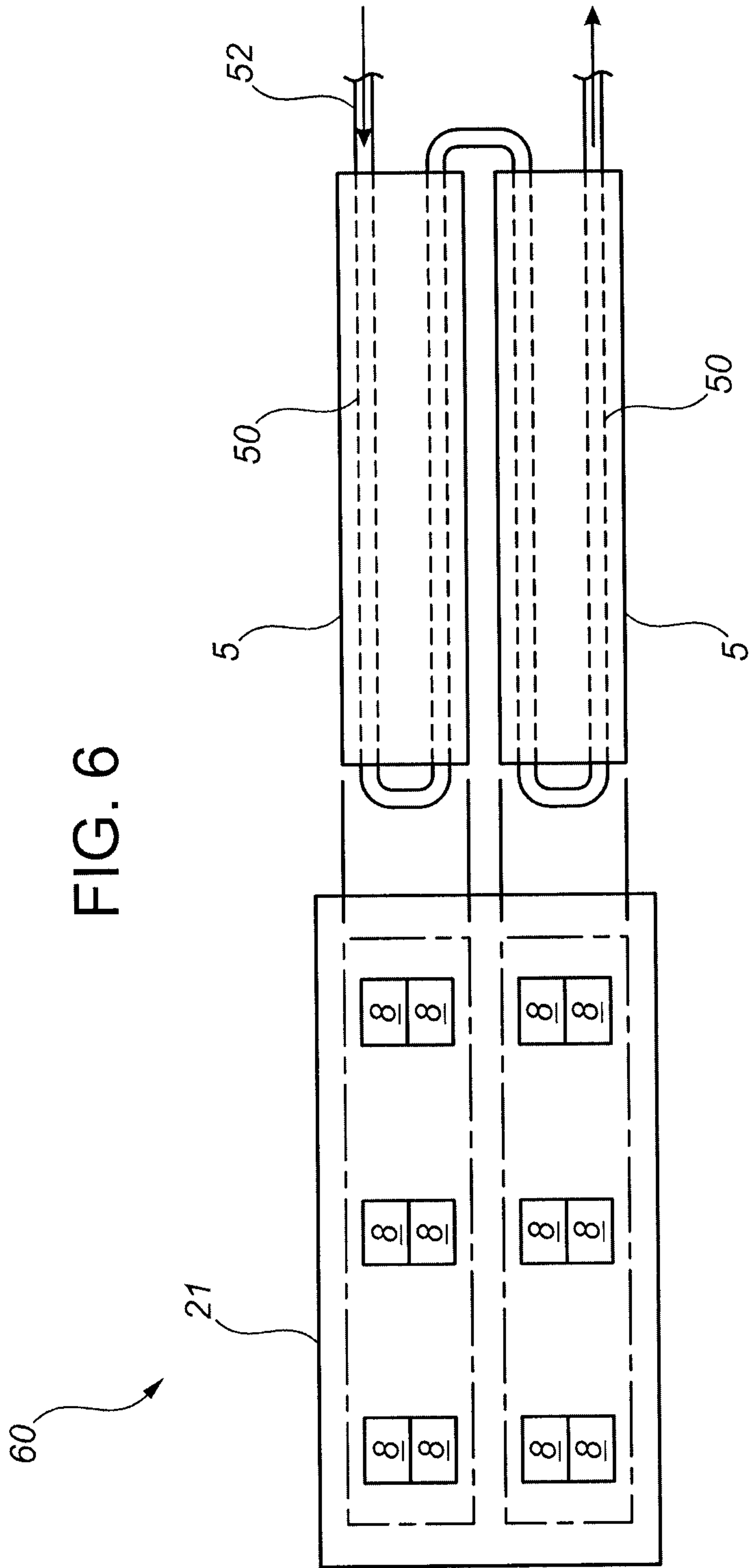


FIG. 5



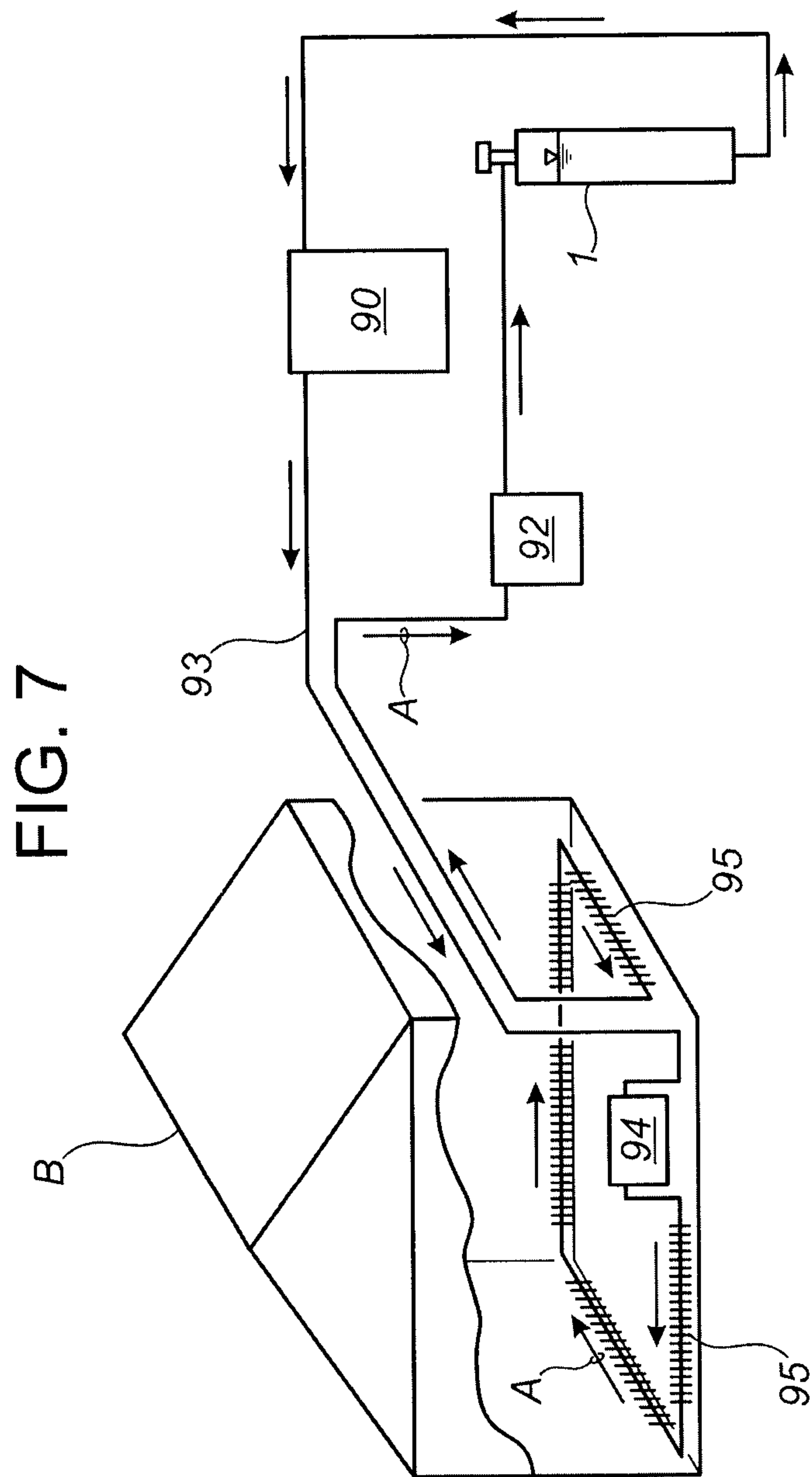


FIG. 8

