(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 February 2016 (11.02.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/020706 Al

(51) International Patent Classification:
F01K 25/08 (2006.01) *F25B 30/02* (2006.01)
F25B 27/00 (2006.01)

(21) International Application Number:
PCT/GB2015/052304

(22) International Filing Date:
10 August 2015 (10.08.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1414077.6 8 August 2014 (08.08.2014) GB
1511148.7 24 June 2015 (24.06.2015) GB

(72) Inventor; and
(71) Applicant : **PLUCINSKI, Andrzej** [PL/GB]; 79 Clays Road, Walton-on-the-Naze, Essex CO14 8SD (GB).

(74) Agent: **SANDERSON & CO;** 34 East Stockwell Street, Colchester, Essex CO1 1ST (GB).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available):* AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available):* ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

(54) **Title:** THERMODYNAMIC SYSTEM FOR POWERING AN ENGINE USING AN EXTERNAL THERMAL ENERGY SOURCE

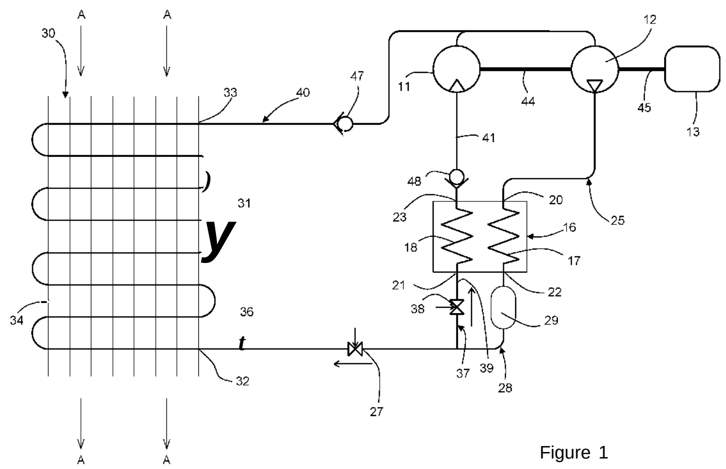

Figure 1

(57) **Abstract:** A thermodynamic system and method of operating such a system, to absorb thermal energy originating externally of the system and power an engine. The system comprises a heat absorber (30) arranged to absorb external thermal energy by heating cooler working fluid passed through the absorber, a compressor (12) arranged to compress gaseous working fluid supplied thereto from the heat absorber. A heat exchanger (16) has first (17) and second (18) thermally-linked fluid paths, the compressor being connected to the first fluid path (17) to transfer heat from the compressed working fluid to cooler working fluid in the second fluid path (18). First (27) and second expansion valves (28) are arranged to expand and so cool respective portions of cooled working fluid from the first fluid path (17) and supply the expanded and further cooled portions to the heat absorber and to the second fluid path (18) of the heat exchanger, to absorb heat from the first fluid path (17). A vapour-powered engine (11) is drivingly connected to the compressor, fluid from the downstream end (23) of the second fluid path (18) of the heat exchanger 16 being supplied directly or indirectly to the engine (11) whereby the supplied fluid effects the operation thereof. Fluid from the downstream end of the heat absorber (30) is supplied either directly or indirectly to the engine (11) or directly or indirectly to the compressor (12).

WO 2016/020706 A1

THERMODYNAMIC SYSTEM FOR POWERING AN ENGINE USING AN EXTERNAL THERMAL ENERGY SOURCE

This invention relates to a thermodynamic system including an engine powered by an external source of thermal energy, typically at a relatively low temperature, and also to a method of powering an engine from a source of thermal energy. In particular (but not exclusively), the invention allows the conversion of the absorbed thermal energy to mechanical or electrical work, the environment serving as a low temperature source of thermal energy.

Electricity is predominantly generated using non-renewable sources such as coal, natural gas and nuclear energy. The vast infrastructure and efforts required to mine and deliver coal and gas to power stations is economically and environmentally damaging. The fuel produced is not only expensive but is also highly pollutant, creating dangerous effluents and carbon dioxide. Nuclear power plants require large investments and a serious failure can cause a disaster on an epic scale. Additionally, nuclear power creates additional problems associated with disposal of radioactive waste. Renewable forms of energy account for a small percentage of overall power generation but suffer from reliance on varying environmental factors. Even advanced methods of producing electric power are not free from disadvantages.

It is a principal aim of the present invention to address at least some of the above problems and to provide apparatus and a method including an engine for producing power (in some embodiments) which is environmentally friendly, efficient and safer than the above discussed existing technologies, by using relatively low temperature sources such as the ambient air.

According to one aspect of this invention, there is provided a thermodynamic system for absorbing thermal energy originating externally of the system and converting the absorbed energy into mechanical work, comprising:

- a heat absorber arranged to absorb thermal energy originating externally of the system by heating cooler working fluid passed through the absorber;

- a compressor arranged to compress gaseous working fluid supplied thereto directly or indirectly from the heat absorber;

- a heat exchanger having first and second thermally-linked fluid paths, the compressor being connected to the first fluid path to transfer heat from the compressed working fluid to cooler working fluid in the second fluid path;

- at least one expansion valve arranged to expand and thereby further to cool cooled working fluid from the first fluid path and supply the expanded and further cooled fluid to the heat absorber and also to the second fluid path to absorb heat from the first fluid path;

- a vapour-powered engine drivingly connected to the compressor; and

- a fluid pathway from the downstream end of the second fluid path of the heat exchanger leading directly or indirectly to the engine whereby the heated fluid effects the operation thereof.

According to a second but closely related aspect of this invention, there is provided a method of powering an engine by absorbing thermal energy from externally of the system and converting the absorbed energy to mechanical work, the method comprising the steps of:

- absorbing thermal energy originating externally of the system by passing working fluid through a heat absorber, said fluid entering the heat absorber at a lower temperature than the temperature of the external thermal energy;

- compressing gaseous working fluid supplied to a compressor directly or indirectly from the heat absorber;

- directing the compressed working fluid to a first fluid path of a heat exchanger, the heat exchanger having a second fluid path thermally-linked to the first fluid path so that heat from the compressed fluid supplied to the first fluid path is transferred to cooler working fluid in the second fluid path;

- expanding and further cooling cooled working fluid from the first fluid path of the heat exchanger and suppling the expanded and further cooled fluid to the heat absorber and also to the second fluid path to absorb heat from the first fluid path whereby working fluid supplied to the heat absorber absorbs heat from externally of the system and the working fluid supplied to the second fluid path of the heat exchanger absorbs heat from the first fluid path;

- supplying the heated working fluid from the second fluid path of the heat exchanger directly or indirectly to a vapour-powered engine to effect the operation; and

- driving the compressor by the vapour-powered engine thereby to effect compression of the working fluid supplied to the compressor.

In the thermodynamic system of this invention, a working fluid (heat exchange fluid, such as a refrigerant) is constrained to flow around a closed loop circuit, and absorb energy from a relatively low temperature source, such as the environment. It will be appreciated that the working fluid used in this invention must be capable of flowing and of being compressed when in a gaseous phase to a liquid phase, and once compressed, of being expanded again back to a gaseous phase. When compressed to a liquid, the temperature will rise and if then expanded adiabatically back to a gaseous phase there will be a consequent drop in temperature. The principles and thermodynamic properties of the gaseous and liquid phases of a compressible fluid such as a refrigerant are well known in the art and will not be explained in detail here.

The system relies on the transfer of relatively low temperature thermal energy from the environment to the fluid when expanded to be cooler, and preferably significantly cooler, than the ambient as the fluid is circulated through the heat absorber. Thus, the references herein to a relatively low temperature are intended to mean temperatures which may be encountered naturally in the environment, such as the temperature of the ambient air or the temperature of water in a water course or the like, and which are much lower than the temperatures encountered when burning a hydrocarbon or similar fuel.

By appropriate configuration of the pathways for the fluid downstream of the first fluid path of the first heat exchanger, various configurations of this invention are possible. In the most preferred arrangement, the cooled fluid from the first fluid path of the first heat exchanger is divided so that a first portion is directed to the heat absorber, and a second portion is directed to the second fluid path of first heat exchanger. In this arrangement, the first portion may subsequently be mixed with the second portion, either before that second portion passes through the second path of the first heat exchanger (in which case all of the flow will pass through the second path of the first heat exchanger), or after that second portion has passed through the second path of the first heat exchanger. In either of these cases, a single expansion valve may be provided downstream of the first fluid path through the first heat exchanger, or two separate expansion valves may be provided disposed downstream of the separation of the fluid flow into said first and second portions, respectively one for each portion of the fluid flow.

To give effect to this preferred arrangement, the system may comprise a fluid pathway from the first expansion valve to the upstream end of the heat absorber; and another fluid pathway from the downstream end of the heat absorber directly or indirectly to the engine. Further, there may be another fluid pathway from the downstream end of the first fluid path directly or indirectly to the upstream end of the second fluid path of the first heat exchanger; and yet another fluid pathway from the downstream end of the second fluid path to the engine.

Other possible configurations for the system of this invention include:

- All of the fluid expanded by the first expansion valve may pass through the second path of the first heat exchanger and then through the heat absorber, before being supplied to the engine.
- All of the fluid expanded by the first expansion valve may pass through the heat absorber and then through the second path of the first heat exchanger, before being supplied to the engine.

To give effect to the second possible arrangement mentioned above, the system may have a fluid pathway from the first expansion valve to the upstream end of the second fluid path of the first heat exchanger; a fluid pathway from the downstream end of the second fluid path of the first heat exchanger; and another fluid path from the downstream end of the heat absorber to the engine.

As mentioned above, a portion of the compressed and cooled fluid supplied from the downstream end of the first fluid path may be supplied to the heat absorber, the remaining portion being supplied to the upstream end of the second fluid path of the first heat exchanger, after being further cooled on passing through the second expansion valve. The lower the temperature of fluid passing through the second fluid path the more efficient the heat transfer within the first heat exchanger, with the fluid absorbing heat from the fluid flowing along the first fluid path.

In an alternative arrangement, no second expansion valve is provided. In this case the entirety of the fluid flow leaving the first fluid path of the first heat exchanger passes through the first expansion valve and then through the heat absorber before being supplied to the second fluid path of the first heat exchanger.

The heat absorber is in effect a heat exchanger which may comprise an element through which the fluid flows, the element being exposed to the environmental heat energy source. In this arrangement the first expansion valve serves to convert the high pressure liquid phase of the fluid to the vapour (gaseous) phase with a consequent drop in temperature. The cooled fluid is constrained to flow through the element, with the element being arranged to absorb heat from the surroundings. The surroundings may be ambient air or water caused to flow over the element, or could even be the earth itself (i.e. geothermal energy).

Preferably, the portion of the compressed and cooled fluid from the downstream end of the first fluid path is expanded by the first expansion valve such that the temperature of that fluid after expansion and supplied to the heat absorber is less than the temperature of the surroundings. The greater the difference between the temperature of the surroundings and the temperature of fluid entering the heat absorber the better, as this increases the heat transfer from the environment and makes the overall system more efficient. The surroundings preferably comprise air caused to flow over the heat absorber. In this way the system utilises heat energy indirectly from the sun. Unlike many existing technologies which rely on pollutant fossil and radioactive fuels, the system and method of this invention utilises energy from the sun which is stored in the atmosphere or environmental water as heat.

In another arrangement, the system may further comprise a second compressor arranged to compress gaseous fluid from the downstream end of the heat absorber, whereby the fluid is compressed and so also heated, before being supplied to the engine. The second compressor draws fluid from the second heat exchanger so lowering the pressure and temperature therein, and thus separates the low pressure area of the second heat exchanger from the high pressure area of the vapour engine. This arrangement is particularly beneficial in low temperature environments where the air temperature may be sub-zero, to increase the efficiency of the system. The second compressor serves to convert fast-flowing low pressure fluid flow to slow-flowing, high pressure and relatively hot flow.

The first heat exchanger serves to liquefy by cooling the gas supplied thereto under high pressure from the compressor; and at the same time the first heat exchanger utilises the waste heat energy acquired from the compressed gas to raise the pressure at the inlet to the vapour engine, in conjunction with the increase in pressure in the gas arising from the gas being heated by the ambient air in the second heat exchanger. In one embodiment the heat exchanger and heat absorber operate in parallel to provide gas under pressure to the vapour engine, and in another embodiment the heat exchanger and heat absorber operate in series. The provision of a second compressor arranged in the fluid path immediately before the vapour engine, as described above, serves to lower the pressure downstream of the expansion valve (or valves if two are provided), increases the pressure at the engine inlet and separates the low pressure areas of the heat exchangers from the high pressure area of the vapour engine. It is to be noted that the energy provided by the engine for driving the second compressor is recovered (subject to the efficiency of the system) by the increased pressure at the engine inlet.

At present, conventional coolers and heaters based on heat pump principles require energy to be delivered from an external source and at the same time, in the case of coolers, surplus heat is expelled as wasted energy. Preferably, the vapour engine (otherwise referred to as a pneumatic motor, but here not running on compressed air) of this invention is drivingly coupled to the second compressor such that the second compressor is driven thereby. In this way, the present invention utilises energy which otherwise would be wasted to power the first compressor, and if provided, also the second compressor.

In one embodiment, the system may be arranged to provide air conditioning by including another heat exchanger for the hot fluid leaving the compressor. In this arrangement, the relatively hot compressed fluid from the first compressor is cooled in the third heat exchanger by dumping some of that heat to the environment before the fluid is passed to the upstream end of the first fluid path of the first heat exchanger. The fluid passing through the heat absorber is relatively cold and absorbs heat from the environment. Thus by providing the system with appropriate air ducts, the system may be used as an air conditioning unit, able to cool and then reheat the ambient air or allow the heat to be used for domestic or other purposes.

One or more unidirectional valves may be arranged in the system to control the direction of fluid flow. A unidirectional valve may be disposed in the fluid pathway from the downstream end of the second fluid path to allow flow only towards the engine.

The fluid pathway from the downstream end of the heat absorber may extend to the upstream end of the second fluid path of the first heat exchanger and so indirectly to the engine. In this alternative arrangement, heated fluid from the heat absorber is added to the fluid supplied to the upstream end of the second fluid path of the first heat exchanger, thus creating a single pathway for the fluid to the engine from the downstream end of the second fluid path of the first heat exchanger.

The system may further comprise a tank for accumulating the liquid phase of the compressed fluid, the tank being connected in the pathway between the downstream end of the first fluid path, the first expansion valve and the upstream end of the second fluid path. The tank should be arranged to store liquid phase fluid passing from the downstream end of the first fluid path to the first expansion valve (and second expansion valve, if provided), to ensure only liquid is expanded by the or each expansion valve and prevent any gaseous phase passing through the valve. This optimises the expansion process to cool the fluid to the greatest possible extent and ensures stable operation which otherwise might not occur should bubbles pass through the valve.

The engine of the system may be arranged to drive a load, in addition to the first compressor. The load may be a mechanical device (such as a pump), or may comprise a generator for electricity which could be used for any conventional purpose or could be used to dump energy in the form of heat, for example as space heating, without the need to employ a third heat exchanger as described above.

A unidirectional valve may be disposed in the fourth fluid pathway to allow fluid from the downstream end of the second heat exchanger to flow only towards the engine.

Preferably, the fluid comprises a refrigerant having a relatively low boiling point. An example of a suitable refrigerant is marketed under the name R410A; this gas has a boiling point of -48.5°C at 1 atm. At -25°C this refrigerant gas is 23.5°C above its boiling point and has a vapour pressure of 2.3 atm. With the gas at -25°C, it is able to absorb heat energy from the ambient air, the temperature of which (i.e. of the surroundings) need not be high.

It will be appreciated that in the system of this invention, the air entering the heat absorber will be at ambient temperature and will leave the heat absorber at a sub-ambient temperature after imparting thermal energy to the relatively cold fluid in the heat absorber. It is possible to raise the temperature of the air exiting the heat absorber to ambient by providing a heat source arranged to pre-heat the air supplied to the heat absorber. Such a heat source may, for example, comprise an alcohol burner arranged to pre-heat the ambient air supplied to the heat absorber. In this way, the system may have a zero heat signature which would be very hard to detect by an infra-red or thermal imaging camera. This could be useful for defence applications, such as for use in aircraft or other vehicles. This arrangement may also be useful in extremely cold environments where the efficiency of the system may otherwise be compromised by the incoming ambient air having a temperature only slightly above that of the fluid supplied to the heat absorber.

Instead of using an alcohol burner as just-described, the source of the heat could be an internal combustion engine which otherwise would dump heat to the environment by way of a radiator and the engine exhaust system. Using the waste heat from such an engine in conjunction with the system of this invention would allow the range of a hybrid car to be extended. It would also significantly lower the carbon emissions per kilometre released to atmosphere.

By way of example only, embodiments of thermodynamic systems including an engine powered by a low temperature source of thermal energy and arranged in accordance with this invention will now be described in detail, reference being made to the accompanying drawings in which:-

Figure 1 is a simplified diagrammatic view of the first embodiment of thermodynamic system of this invention;

Figure 2 diagrammatically shows the temperatures of the working heat exchange fluid (refrigerant) circulating within the embodiment of Figure 1;

Figure 3 is a simplified diagrammatic view of a first modified form of the first embodiment;

Figure 4 diagrammatically shows the temperatures of the working fluid (refrigerant) circulating within the embodiment of Figure 3;

Figure 5 shows in diagrammatic form an alternative arrangement for the first modified form of the first embodiment, shown in Figure 3;

Figure 6 diagrammatically shows the temperatures of the working fluid (refrigerant) circulating within the embodiment of Figure 4;

Figure 7 is a simplified diagrammatic view of a second modified form of the first embodiment;

Figure 8 is a simplified diagrammatic view of a third modified form of the first embodiment, using two compressors;

Figures 9, 10 and 11 respectively show the temperatures, pressures and densities of the working fluid (refrigerant) circulating within the embodiment of Figure 8;

Figure 12 is a simplified diagrammatic view of a second embodiment of thermodynamic system of this invention, using two compressors and a heat dump heat exchanger;

Figure 13 diagrammatically shows the temperatures of the working fluid (refrigerant) within the second embodiment of Figure 12; and

Figure 14 shows a further arrangement equivalent to the embodiment of Figure 10, but having only one compressor. .

Throughout the following description of the various embodiments and methods of thermodynamic system of this invention, the same reference numbers are used to designate the same, or equivalent, components. Further, only the first embodiment will be described in detail and reference should be made as necessary to that embodiment for a full understanding of the subsequently-described embodiments.

Referring initially to Figure 1 there is shown, in simplified diagrammatic form, a first embodiment of a thermodynamic system including an engine 11 powered by energy extracted from the ambient - that is, a relatively low temperature source of thermal energy. The engine 11 is powered by pressurised vapour of a refrigerant serving as a heat-exchange working fluid and is equivalent to a pneumatic motor powered by compressed air, and so could comprise for example a rotary-vane motor, a piston motor or a turbine. The engine 11 is drivingly coupled to a compressor 12, which in turn is coupled by a common shaft 44, 45 to a mechanical or electrical load 13. The mechanical load could be for example a pump, or the electrical load could be for example an alternator. The thermodynamic system comprises a closed-loop circuit around which the refrigerant working fluid is arranged to flow, in a gaseous phase or a liquid phase.

The system comprises two heat exchangers 16, 30. The first heat exchanger 16 shown in Figure 1 comprises first and second fluid paths 17, 18 which are thermally-linked to allow heat transfer from warmer fluid in one path to cooler fluid in the other path, so cooling the warmer fluid and heating the cooler fluid. Each of the first and second fluid paths 17, 18 has an upstream end 20, 21 for the flow of fluid into the respective fluid path and a downstream end 22, 23 for the flow of fluid out of the respective path. In the case of this embodiment, the flow through the path 17 is at a higher temperature than the flow through path 18, and so heat is transferred from the fluid in path 17 to the fluid in path 18.

The compressor 12 is arranged to compress the working fluid supplied thereto, thereby raising the temperature of the fluid. The compressed and heated fluid from the compressor 12 is supplied along pathway 25 to the upstream end 20 of the first fluid path 17 of the first heat exchanger 16 so that hot, compressed fluid from the compressor 12 passes along the first fluid path 17. Heat is transferred from the fluid passing through the first fluid path 17 to relatively cold fluid passing along the second fluid path 18, as discussed below;

the fluid passing along the first path 17 is thereby cooled to the liquid phase within the first heat exchanger 16.

A tank 29 accumulates the liquid from the downstream end of the first fluid path 17, to allow any gaseous phase present in that liquid to separate into the upper space of the tank and so not be passed forwards. From the tank 29, a portion of the liquid is supplied along pathway 28 to a first expansion valve 27 and a further portion is supplied along pathway 37 to a second expansion valve 38. Adiabatic expansion of the liquid phase of the fluid in the expansion valves 27 and 38 causes a sudden decrease in temperature as the liquid phase becomes gaseous.

The second heat exchanger 30 includes a fluid element 31 having an upstream end 31 connected to the first expansion valve 27 by fluid pathway 36, and a downstream end 33. The element 31 is provided with fins 34 to assist the transfer of heat from the warmer ambient air to the cooler fluid in the element 31, the ambient air being caused to pass over the element 31, as shown by arrows A. The system 10 is configured such that the fluid from the first expansion valve 27 comprises boiling liquid and saturated gas at a temperature significantly less than the temperature of the air A flowing over the second heat exchanger 30 so that as fluid passes through the element 31 the temperature and pressure thereof increase. Superheated fluid vapour leaves the downstream end 33 of the heat exchanger 30 and is supplied along pathway 41 to the compressor 12, through a non-return valve 47, for recirculation around the system.

In a similar way, the portion of fluid from the downstream end 22 of the first fluid path 17 supplied to the second expansion valve 38 is expanded thereby to form boiling liquid and saturated gas which passes along pathway 39 to the upstream end 21 of the second path 18 of the first heat exchanger. The temperature of that boiling liquid and saturated gas is significantly lower than the temperature of the fluid in the first path 17 of that heat exchanger. As that fluid passes along the second path 18, the temperature and pressure thereof increase and superheated fluid vapour leaves the downstream end 23 of that path 18. The utilisation of the second expansion valve 38 increases the efficiency of heat transfer between the first and second fluid paths 17, 18 of the first heat exchanger 16 by increasing the temperature differential.

Fluid from the downstream end 23 of the second fluid path 18 of the first heat exchanger 16 is supplied along pathway 41 provided with a non-return valve 48 to the vapour engine 11, which is arranged to convert the thermodynamic energy of the fluid to mechanical energy. The engine 11 is connected to the compressor 12 by a mechanical shaft 44 and to the load 13 by a further shaft 45. The exhausted fluid from the engine 11 is mixed with the fluid from the downstream end 33 of the heat exchanger 30 and is fed to the compressor 12, for recirculation around the system as has been described above.

The work performed by the engine 11 results the fluid exhausted from the engine and supplied to the compressor 12 being at a low temperature and low pressure, the fluid being subsequently compressed by the first compressor 12 to increase the fluid density and temperature, as described above. The non-return (unidirectional) valves 47 and 48 serve to ensure there will be no back-flow either to the first heat exchanger 16 or the second heat exchanger 30, in the event the pressures of the fluid leaving those heat exchangers are not exactly the same. Thus, fluid from those heat exchangers can flow only to the engine 11.

Figure 2 shows the temperatures of the working fluid (refrigerant) within the system described above, as the fluid circulates therearound. Higher temperatures are shown by darker shading; and lower temperatures are shown by lighter shading.

From the above description of this embodiment, it will be appreciated that the heat absorber 30 has to have to have a temperature lower than that of the immediate environment. To induce this low temperature, the thermodynamic property of the latent heat of evaporation is used in the working fluid circulating in the system. The evaporation (changing the state from a liquid to a gas) lowers the temperature of the heat absorber so as to cause the flow of heat (energy) from outside to within the system. The evaporation takes place when liquid passes through the expansion valve 27 and enters the space within the absorber, which has to be at a lower pressure. If low pressure in the absorber is secured, the boiling liquid lowers the temperature of the absorber, allowing the flow of heat energy to the system, even from a cold environment.

The heat acquired by the absorber causes expansion of the gas, increasing its pressure but to preserve the requirement for a low pressure in the absorber the gas is removed by the compressor 12. This compressor converts the low pressure, low temperature and high volume gas to high pressure, high temperature and low volume gas.

This hot gas is directed to the fluid path 17 serving as a heat emitter of the heat exchanger 16 where heat is transferred to the fluid path 18 serving as a collector. The fluid in path 17 loses its temperature and changes its state to liquid, which is collected in the tank 29.

This process encapsulates the gathering of relatively low temperature heat energy from environment and accumulating that energy at a high temperature in the heat emitter 17 of the heat exchanger 16.

The heat transferred from the heat emitter 17 to the heat collector 18 of the heat exchanger 16 is used to boil the liquid which is supplied through valve 38. This raises the pressure of the gas in the heat collector 18, which drives the vapour motor 11. As a result of converting the pressure of the gas into mechanical work, the gas leaving the vapour motor has lower temperature and lower pressure and its residual energy is recovered by injecting the gas to the inlet of the compressor, back into the system.

The output of the vapour motor 11 is used to drive the compressor 12 and also any other appliance like a pump, a compressor, a self-propelled vehicle, a cooling blower or an electricity generator. It will be appreciated that this is done without the system having to discharge any waste heat back to the environment.

Referring now to Figures 3 and 4, there is shown a first modified form of the first embodiment described above, for generating mechanical or electrical energy. In this modified embodiment, the gaseous phase of the working fluid from the first heat exchanger 16 and from the second heat exchanger 30 are mixed before the engine 11. Thus, as shown, the downstream sides of the unidirectional valves 47 and 48 are connected together and then to the inlet side of the engine 11. As shown in Figure 4, this allows for greater heating of the fluid in the heat exchanger 30, as compared to the temperature of the working fluid leaving the heat exchanger 30 in the first embodiment. This system powers the motor with fast flowing refrigerant at low pressure, which arises from the parallel connection of the heat absorber 30 and fluid path 18 of heat exchanger 16.

Figures 5 and 6 show a second modified form of the first embodiment. Heated fluid from the downstream end 33 of the second heat exchanger 30 is supplied to the second fluid path 18 of the first heat exchanger 16 rather than directly to the compressor (as in the first embodiment) or to the engine 11 (as in the first modified form). The gaseous fluid from the second heat exchanger 30 is thus mixed with the gaseous fluid passing along the fluid path 18 of the second heat exchanger, as best seen in Figure 6, showing the temperatures of the working fluid (refrigerant) within the system of Figure 5, as the fluid circulates therearound. With this arrangement, it is sufficient to provide only one unidirectional valve 47 downstream of the second heat exchanger 30, as there is only a single fluid flow pathway to the engine 11 from the downstream end 23 of the second fluid path 18 of the first heat exchanger 16. For certain operational parameters, this arrangement may give a better efficiency within the first heat exchanger 16, as there is sub-cooling of the refrigerant on leaving the heat absorber 30.

Figure 7 shows an alternative arrangement of the system of Figure 3. Here, only one expansion valve is provided, in the fluid pathway 39 from the tank 29 to the upstream end 21 of the second path 18 of the first heat exchanger 16; thus the second expansion valve 38 of the Figure 3 arrangement is omitted. In this alternative arrangement the whole of the fluid flow from the first fluid path 16 of the first heat exchanger 17 passes through the tank 29 and then the first expansion valve 27 before passing through the second fluid path 18 of the first heat exchanger 17; and from the downstream end of the second fluid path of the first heat exchanger, the whole of the fluid flow is supplied along pathway 41 to the upstream end 32 of the second heat exchanger 30. Then, from the downstream end 33 of the second heat exchanger 30, the whole of the fluid flow passes to the engine 11 along pathway40 and as such there is no need for any unidirectional valves to be provided. This arrangement may allow the heat exchanger 30 to operate at lower temperatures as compared to the arrangement of Figure 3, in view of the serial arrangement of the fluid path 18 and the heat absorber 30. The gas produced in the fluid path 18 of the heat exchanger 16 is directed to the input of the heat absorber 30, where it is further heated and gas at a relatively low density and high flow velocity is directed to the vapour engine 11.

The arrangement of Figure 7 allows the thermal energy in the fluid leaving the compressor 12 to be cooled by the first heat exchanger which can operate at a very low temperature with no risk of icing because the fluid paths within the first heat exchanger have no contact with moisture in the ambient air (environment). A very low temperature in the first heat exchanger eases the work of the compressor as the low temperature causes contraction of the fluid on becoming a liquid, and thus acts like a suction line. This may be compared to the arrangement of Figure 5, where the second heat exchanger 30 has to be "overcooled" to ensure the gas leaving the second heat exchanger is sufficiently cold to cool down the compressed gas in the first path 17 of the first heat exchanger to ensure the gas therein is liquefied. However, this excessive cooling is likely to cause very significant icing within the second heat exchanger.

Figure 8 shows a further modification of the first embodiment described above, for generating mechanical or electrical energy. This system includes a second compressor 55 also driven by the engine 11, the fluid from the second heat exchanger 30 being supplied along pathway 40 to the second compressor. As the second compressor 55 draws fluid from the second heat exchanger 30, that lowers the pressure therein, which lowers the boiling point temperature in the second heat exchanger, allowing operation with lower ambient air temperatures such as at -30°C. So, at the inlet to the second compressor there is fast flowing, low temperature, high volume 'thin' gas, and at the outlet there is dense (compressed) gas flowing slowly at a high temperature, including the energy given to the compressor, but reclaimed by the engine 11 later anyway. This second compressor 55 makes two separated spaces, satisfying the requirement for low temperature operation - in the heat absorber 30 a low pressure and for the engine 11 a high pressure.

Figures 9, 10 and 11 respectively show the temperatures, pressures and densities of the working fluid (refrigerant) within the system described above with reference to Figure 8, as the fluid circulates therearound. Higher temperatures, pressures and densities are shown by darker shading; and lower temperatures, pressures and densities are shown by lighter shading.

It will be appreciated that a second compressor could be incorporated in the system of Figure 1 or Figure 3 in essentially the same manner as has been described above with reference to the system of Figure 8. Thus, a second compressor, driven by the engine 11, may be incorporated downstream of the two unidirectional valves 47 and 48, in the fluid pathway leading to the engine 11 (Figure 1 or Figure 3). This second compressor will have the same functionality as has been described with reference to the arrangement of Figure 8. Equally, a second compressor driven by the engine may be incorporated in the arrangements of Figures 5 and 7, in each case disposed in the fluid pathway leading to the engine, and immediately upstream thereof. In the case of Figure 5, the second compressor should be disposed in fluid pathway 41, and in the case of Figure 7, in the fluid pathway 40. The functionality of the second compressor is again as has been described above, to separate fast-flowing cool and low density gas drawn from the heat exchanger 16 (Figure 5) or the heat exchanger 30 (Figure 1 or Figure 3) and the slow-flowing, hot and relatively high density gas supplied to the engine 11.

A second embodiment of system of this invention is shown in Figure 12 and differs from the first embodiment and the modifications thereof in that instead of generating mechanical or electrical energy, the system is configured to serve as an air conditioning unit, both to heat ambient air and to effect cooling thereof, but depending upon the precise operational parameters, it might be possible to include an electricity generator driven by the engine 11.

Rather than utilising the heated fluid from the first compressor 12 directly in the first fluid path 17 of the first heat exchanger 16, the fluid is first passed through a third heat exchanger 60. This third heat exchanger 60 is disposed in the first fluid pathway 25 from the compressor 12 and comprises an element 61 through which the fluid is constrained to flow from an upstream end 62 to a downstream end 63. The element 61 is provided with fins 64 to aid the transfer of heat to air driven over the third heat exchanger, as shown by arrows B, from the compressed and heated fluid passing through the element 61. That heated air may then be used for space heating or other purposes as required. Conversely, the second heat exchanger 30 may be used to cool the ambient air; and by treating the ambient air first to cooling with the second heat exchanger 31 to condense out moisture in the air and then reheating that air with the third heat exchanger 60, the full conditioning thereof may be achieved. Figure 13 shows the temperatures of the working fluid (refrigerant) within the system of Figure 12 described above, as the fluid circulates therearound.

Though this second embodiment uses two compressors, it would be possible for it to use only one compressor, in much the same manner as has been described above with reference to the first embodiment of Figure 1 and the modifications thereof described with reference to Figure 3, 5 and 7. Such a system is shown in Figure 14, which includes a third heat exchanger 60 over which air is caused to flow as shown by arrows B. As has been described above with reference to Figure 12, that air flow B will be heated by the hot compressed fluid passing through the element 61 of the heat exchanger 60.

Operation of all of the above described embodiments is initiated by driving the compressor, and possibly also a water pump or a fan to force cool water or air flow through the heat absorber 30. However, the heat absorber could instead absorb heat by the refrigeration of food stores including household refrigerators and freezers, the cooling of other facilities such as an ice rink, or could comprise a part of an air conditioner as has been described above. When the load 13 comprises an electricity generator, the electrical energy can be used to heat water, to recharge a battery, or can be transferred to power distribution network or grid for use as required.

CLAIMS

1. A thermodynamic system for absorbing thermal energy originating externally of the system and converting the absorbed energy into mechanical work, comprising:

- a heat absorber arranged to absorb thermal energy originating externally of the system by heating cooler working fluid passed through the absorber;

- a compressor arranged to compress gaseous working fluid supplied thereto directly or indirectly from the heat absorber;

- a heat exchanger having first and second thermally-linked fluid paths, the compressor being connected to the first fluid path to transfer heat from the compressed working fluid to cooler working fluid in the second fluid path;

- at least one expansion valve arranged to expand and thereby further to cool cooled working fluid from the first fluid path and supply the expanded and further cooled fluid to the heat absorber and also to the second fluid path to absorb heat from the first fluid path;

- a vapour-powered engine drivingly connected to the compressor; and

- a fluid pathway from the downstream end of the second fluid path of the heat exchanger leading directly or indirectly to the engine whereby the heated fluid effects the operation thereof.

2. A thermodynamic system as claimed in claim 1, wherein there are fluid pathways leading from the expansion valve to the second fluid path of the heat exchanger and from said second fluid path to the heat absorber, whereby all the fluid flow from the expansion valve passes in series through said second fluid path and then through the heat absorber.

3. A thermodynamic system as claimed in claim 1, wherein there are fluid pathways leading from the expansion valve both to the second fluid path of the heat exchanger and to the heat absorber, whereby the second fluid path and the heat absorber are in parallel, with both connected to the expansion valve.

4. A thermodynamic system as claimed in claim 1, wherein there are two expansion valves, a first expansion valve being arranged to expand and further cool a first portion of cooled working fluid from the first fluid path and supply the expanded and further cooled fluid to the heat absorber; and a second

expansion valve arranged to expand and further cool a second portion of cooled fluid from the first fluid path and supply the expanded and further cooled fluid to the second fluid path to absorb heat from the first fluid path.

5. A thermodynamic system as claimed in any of the preceding claims, wherein a non-return valve is provided in a fluid pathway from the heat absorber.

6. A thermodynamic system as claimed in claim 5, wherein the fluid pathway from the heat absorber to the compressor leads directly to the compressor from the non-return valve in said pathway.

7. A thermodynamic system as claimed in claim 5, wherein the fluid pathway from the heat absorber to the compressor leads indirectly through the engine to the compressor, from the non-return valve in said pathway,.

8. A thermodynamic system as claimed in any of the preceding claims, wherein a non-return valve is provided in a fluid pathway from the second fluid path of the heat exchanger.

9. A system as claimed in any of the preceding claims, further comprising a tank in a fluid pathway from the first fluid path of the heat exchanger, the tank being arranged to separate any gaseous phase from liquid from the first fluid path of the heat exchanger.

10. A system as claimed in any of the preceding claims, wherein a fluid pathway connects the engine to the compressor, to direct fluid exhausted from the engine to the compressor for compression thereby.

11. A system as claimed in any of the preceding claims, wherein the heat absorber comprises an element through which the working fluid flows, the element being arranged to absorb heat from the surroundings.

12. A system as claimed in any of the preceding claims, further comprising a second compressor arranged to pre-compress the fluid from the heat absorber.

13. A system as claimed in claim 12, wherein the vapour engine is drivingly coupled to the second compressor.

14. A system as claimed in any of the preceding claims, and additionally comprising a further heat exchanger, fluid from the compressor being passed through the further heat exchanger to effect preliminary cooling of that fluid.

15. A system as claimed in claim 14, wherein the further heat exchanger is arranged to effect space heating.

16. A system as claimed in any of claims 1 to 13, and further comprising a load drivingly coupled to the vapour engine.

17. A system as claimed in claim 16, wherein the load comprises a generator for electricity.

18. A system as claimed in any of the preceding claims, wherein the working fluid comprises a refrigerant.

19. A method of powering an engine by absorbing thermal energy from externally of the system and converting the absorbed energy to mechanical work, the method comprising the steps of:

- absorbing thermal energy originating externally of the system by passing working fluid through a heat absorber, said fluid entering the heat absorber at a lower temperature than the temperature of the external thermal energy;

- compressing gaseous working fluid supplied to a compressor directly or indirectly from the heat absorber;

- directing the compressed working fluid to a first fluid path of a heat exchanger, the heat exchanger having a second fluid path thermally-linked to the first fluid path so that heat from the compressed fluid supplied to the first fluid path is transferred to cooler working fluid in the second fluid path;

- expanding and further cooling cooled working fluid from the first fluid path of the heat exchanger and suppling the expanded and further cooled fluid to the heat absorber and also to the second fluid path to absorb heat from the first fluid path whereby working fluid supplied to the heat absorber absorbs heat from externally of the system and the working fluid supplied to the second fluid path of the heat exchanger absorbs heat from the first fluid path;

- supplying the heated working fluid from the second fluid path of the heat exchanger directly or indirectly to a vapour-powered engine to effect the operation; and

- driving the compressor by the vapour-powered engine thereby to effect compression of the working fluid supplied to the compressor.

20. A method as claimed in claim 19, in which all the fluid flow from the expansion valve passes in series through said second fluid path of the heat exchanger and then through the heat absorber.

21. A method as claimed in claim 20, in which the second fluid path and the heat absorber are in parallel, both second fluid path and the heat absorber being connected to the expansion valve.

22. A method as claimed in claim 19, in which a first portion of cooled working fluid from the first fluid path is expanded and thereby further cooled and then supplied to the heat absorber, and a second portion of cooled working fluid from the first fluid path there is expanded and thereby further cooled and then supplied to the second fluid path of the heat exchanger to absorb heat from the first fluid path.

23. A method as claimed in any of claims 19 to 22, in which fluid constrained to flow from the heat absorber to the compressor passes through a non-return valve provided in a fluid pathway from the heat absorber.

24. A method as claimed in any of claims 19 to 22, in which fluid from the heat absorber flows directly to the compressor from the non-return valve in said pathway.

25. A method as claimed in any of claims 19 to 22, in which fluid from the heat absorber flows indirectly to the compressor from the non-return valve, passing through the engine.

26. A method as claimed in any of claims 19 to 25, in which fluid is constrained to flow unidirectionally from the second fluid path of the heat exchanger to the engine by a non-return valve.

27. A method as claimed in any of claims 19 to 26, in which any gaseous phase in the fluid flow from the first fluid path of the heat exchanger is separated from the liquid phase before the expansion of that liquid phase.

28. A method as claimed in any of claims 19 to 27, in which fluid exhausted from the engine is directed to the compressor for compression thereby.

29. A method as claimed in any of claims 19 to 28, in which heat is absorbed from air directed through the heat absorber to increase the temperature of working fluid passing through the absorber.

30. A method as claimed in any of claims 19 to 29, in which fluid from the heat absorber is pre-compressed by a second compressor to separate fast flowing, low temperature, high volume gaseous fluid leaving the heat absorber from dense gas flowing slowly at a high temperature supplied to the engine.

31. A method as claimed in claim 30, in which the second compressor is driven by the vapour engine.

32. A method as claimed in any of claims 19 to 31, in which compressed fluid from the compressor is passed through a further heat exchanger to effect preliminary cooling of that fluid by ambient space heating.

33. A method as claimed in any of claims 19 to 31, in which a mechanical load is coupled to the vapour engine to be driven thereby.

32. A method as claimed in any of claims 19 to 31, in which the engine is drivingly coupled to an electricity generator for the production of electricity.

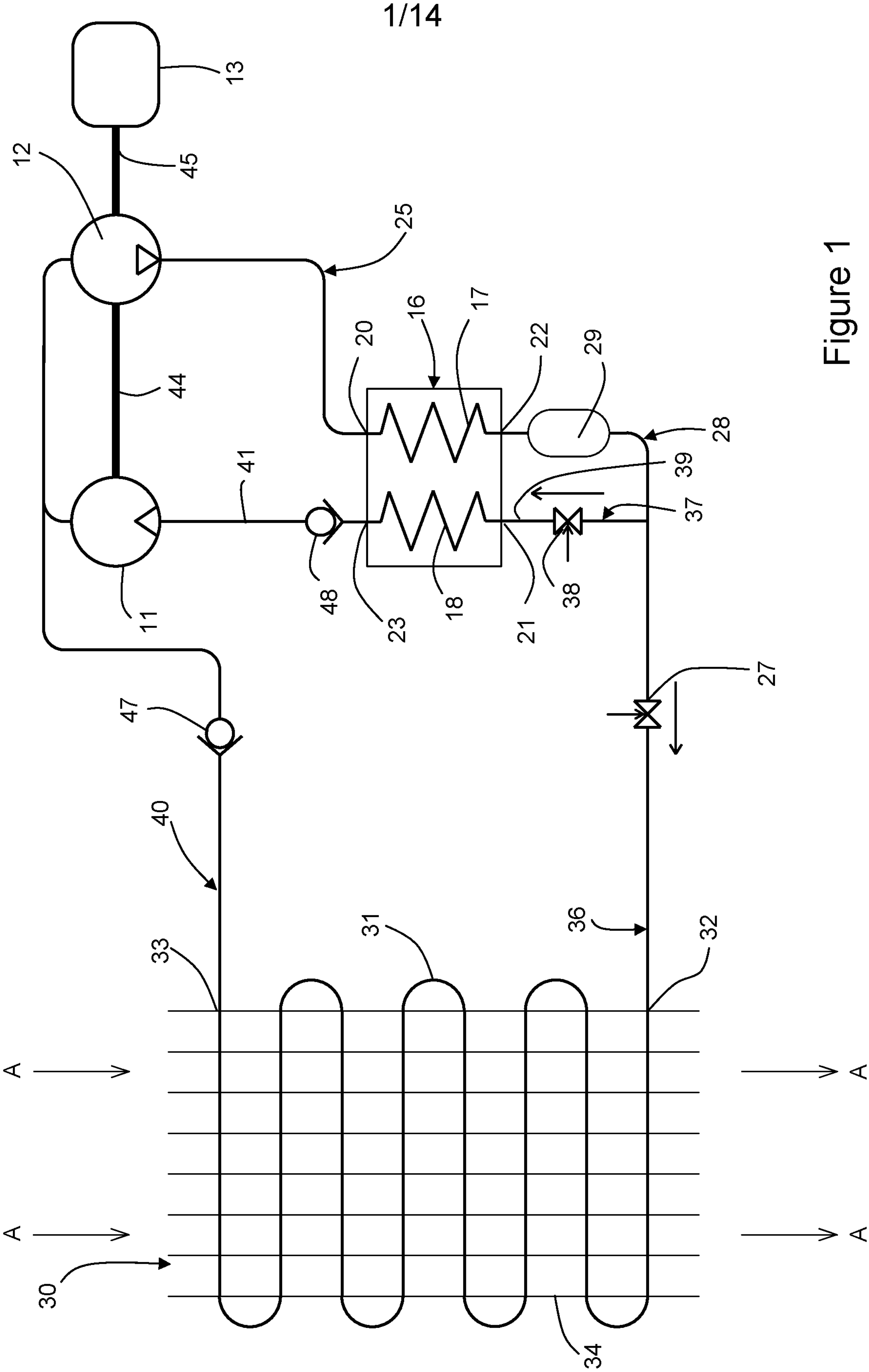
13
12
45
25
44
16
17
20
22
29
28
41
39
37
11
48
23
18
21
38
27
47
40
36
31
33
32
A
A
A
A
30
34

Figure 1

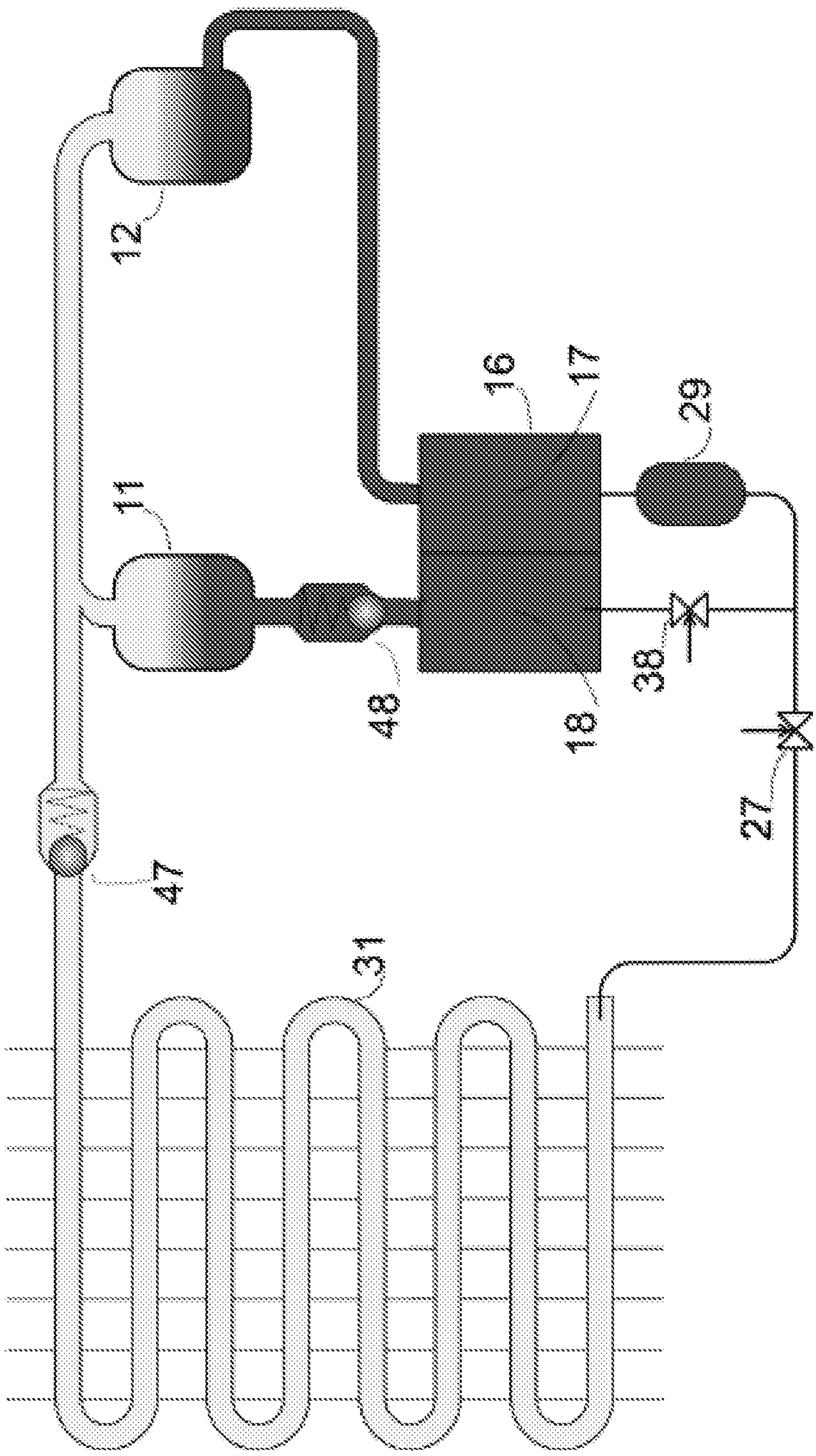

Figure 2

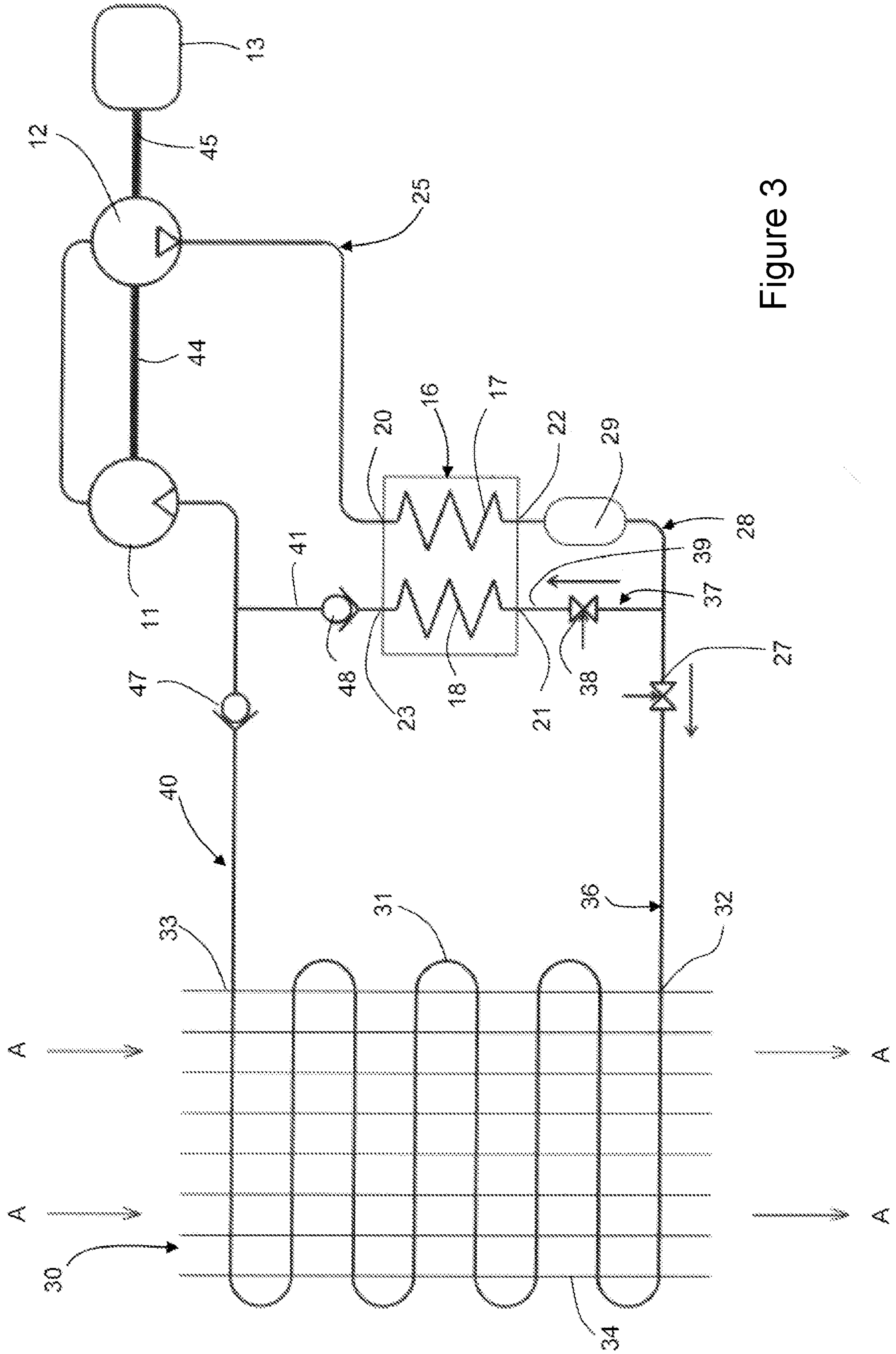
13
12
45
25
44
11
20
16
17
22
29
28
41
39
37
48
47
23
18
21
38
27
40
36
33
31
32
30
34
A
A
A
A

Figure 3

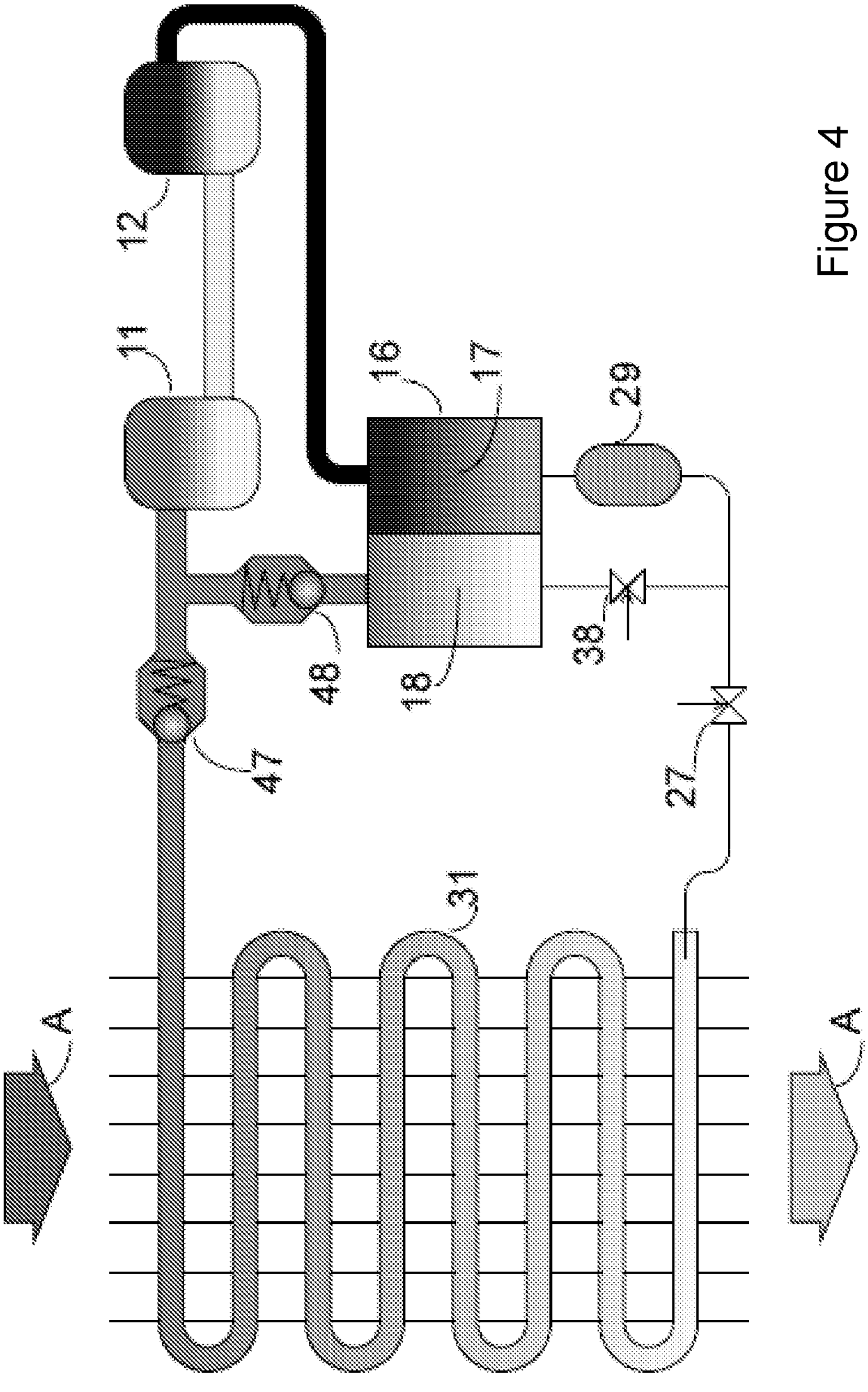

Figure 4

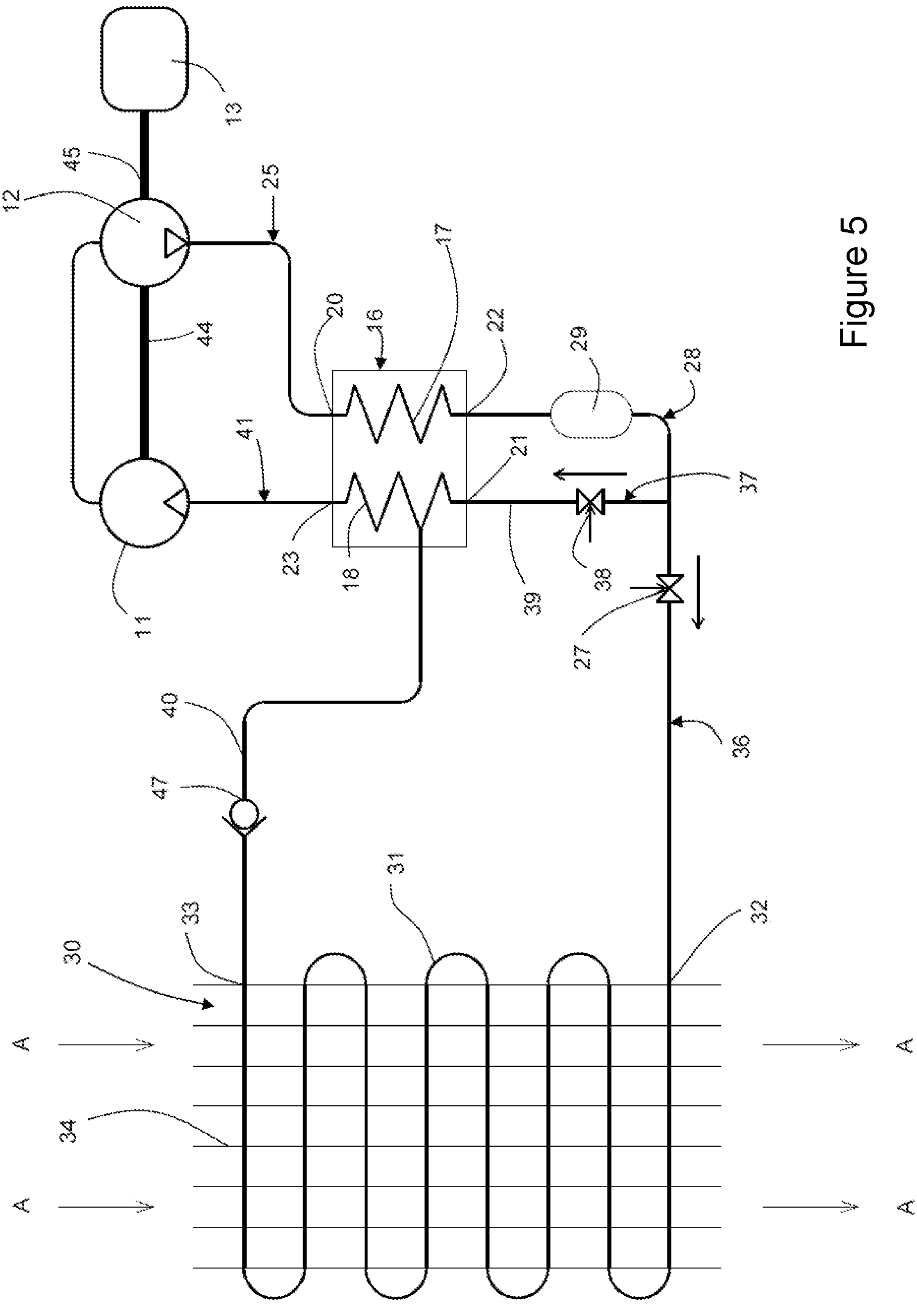
13
45
12
25
17
20
16
22
44
29
28
41
21
37
23
18
39
38
11
27
40
36
47
31
33
32
30
A
A
34
A
A

Figure 5

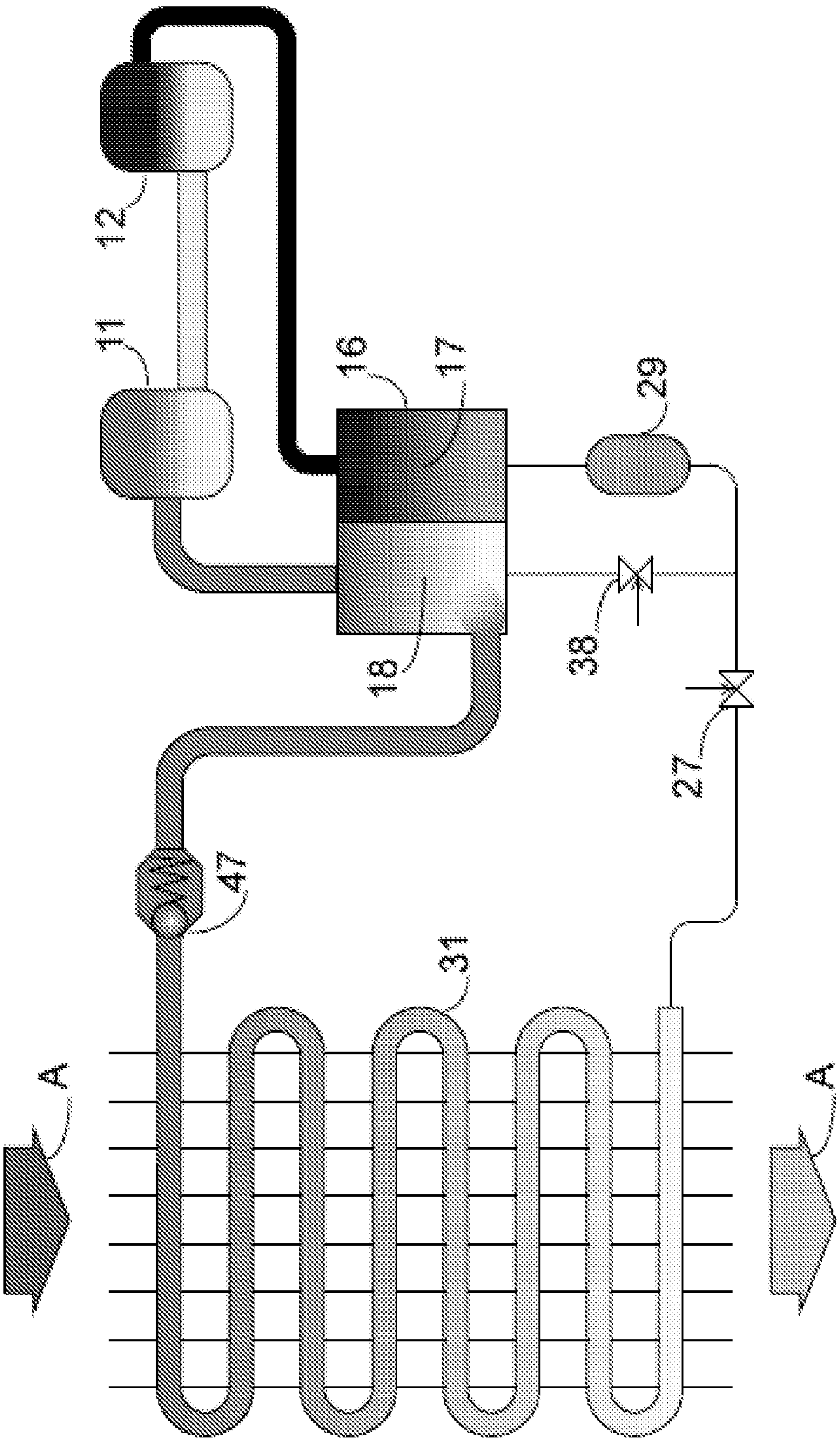

Figure 6

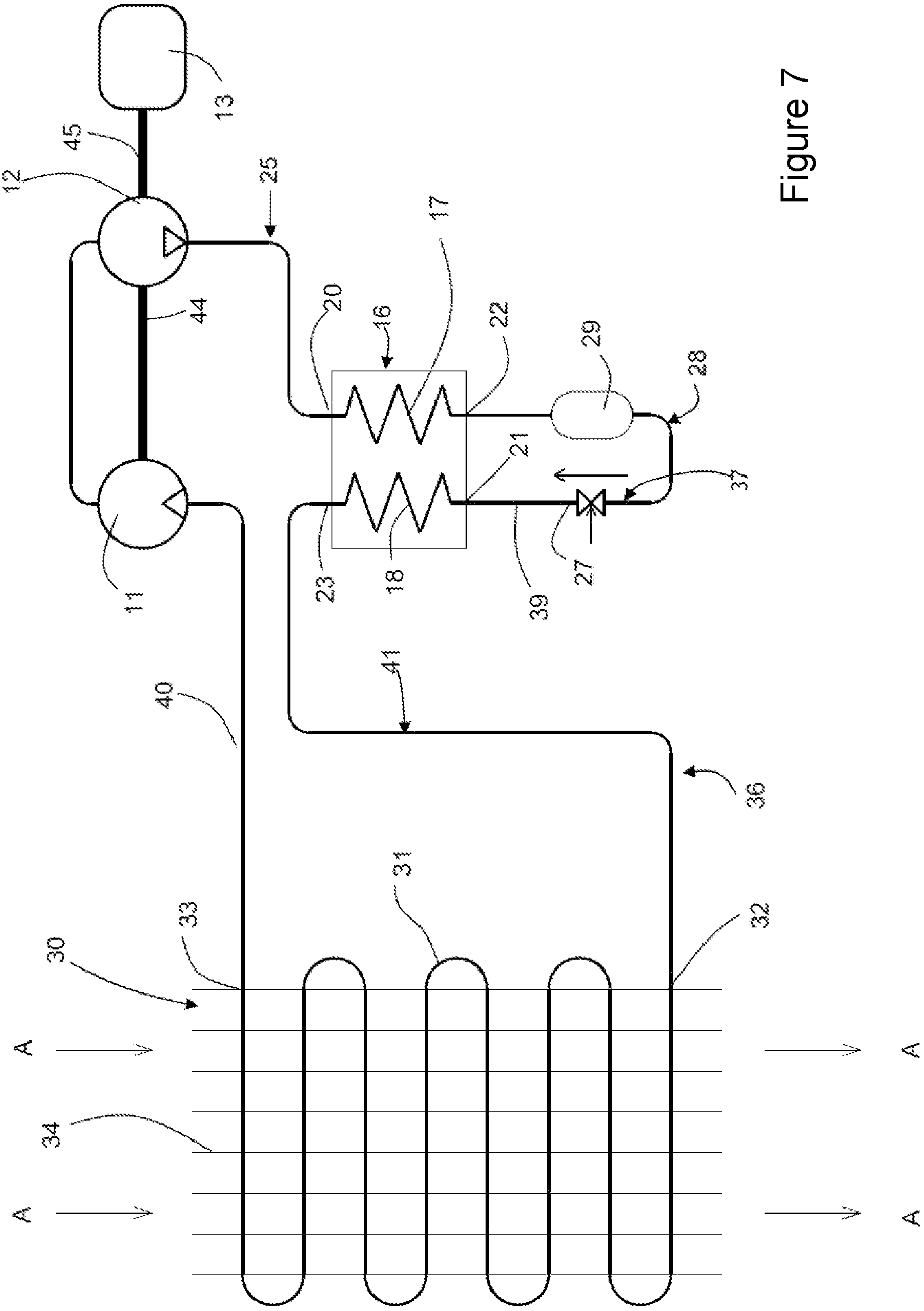
13
45
12
25
17
20
16
22
29
28
44
21
37
11
23
18
39
27
41
40
36
31
33
30
32
34
A
A
A
A

Figure 7

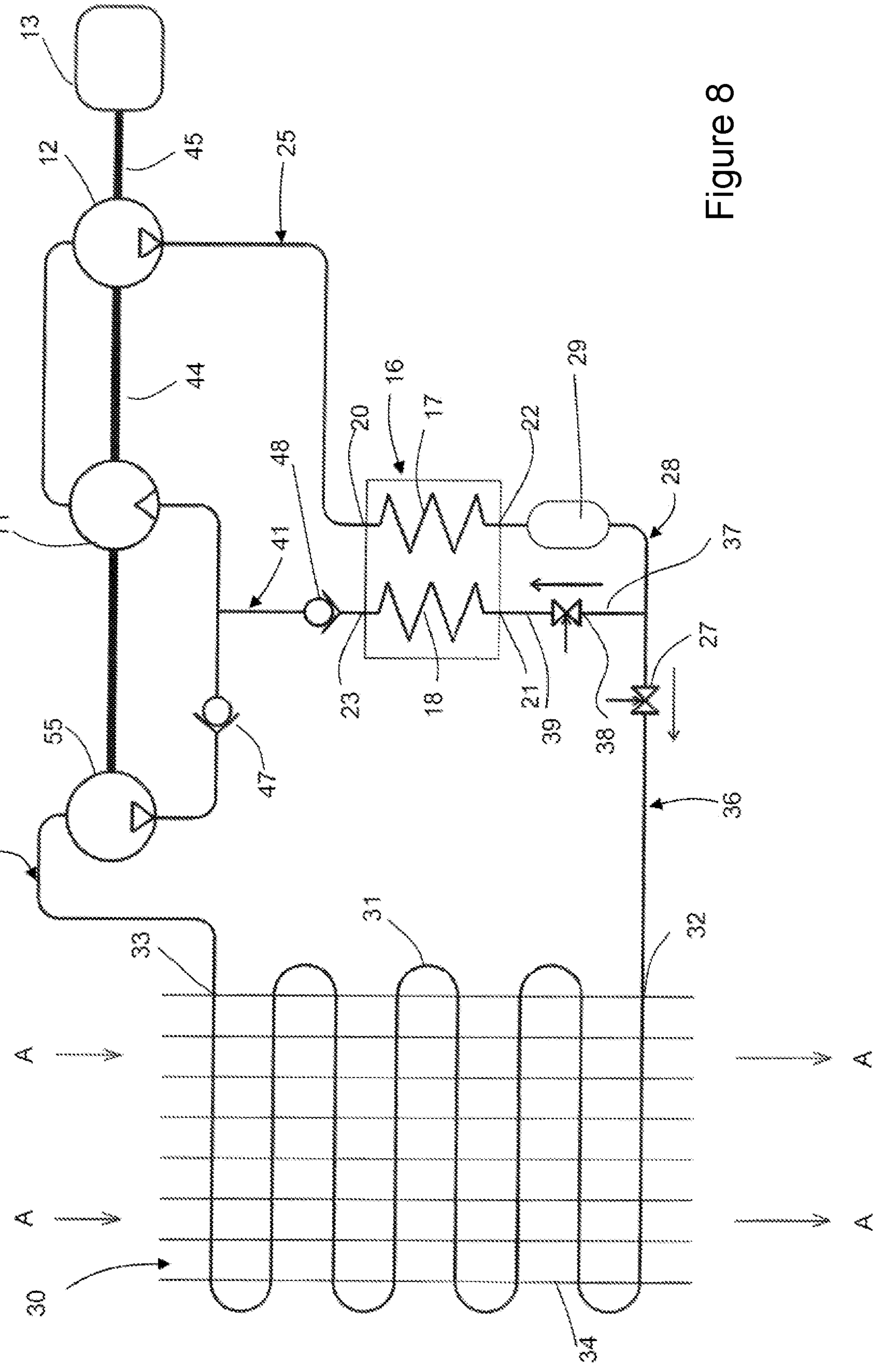
13
12
45
25
44
16
17
29
20
22
48
28
11
41
37
23
18
21
39
38
27
55
47
36
40
31
32
33
30
34
A
A
A
A

Figure 8

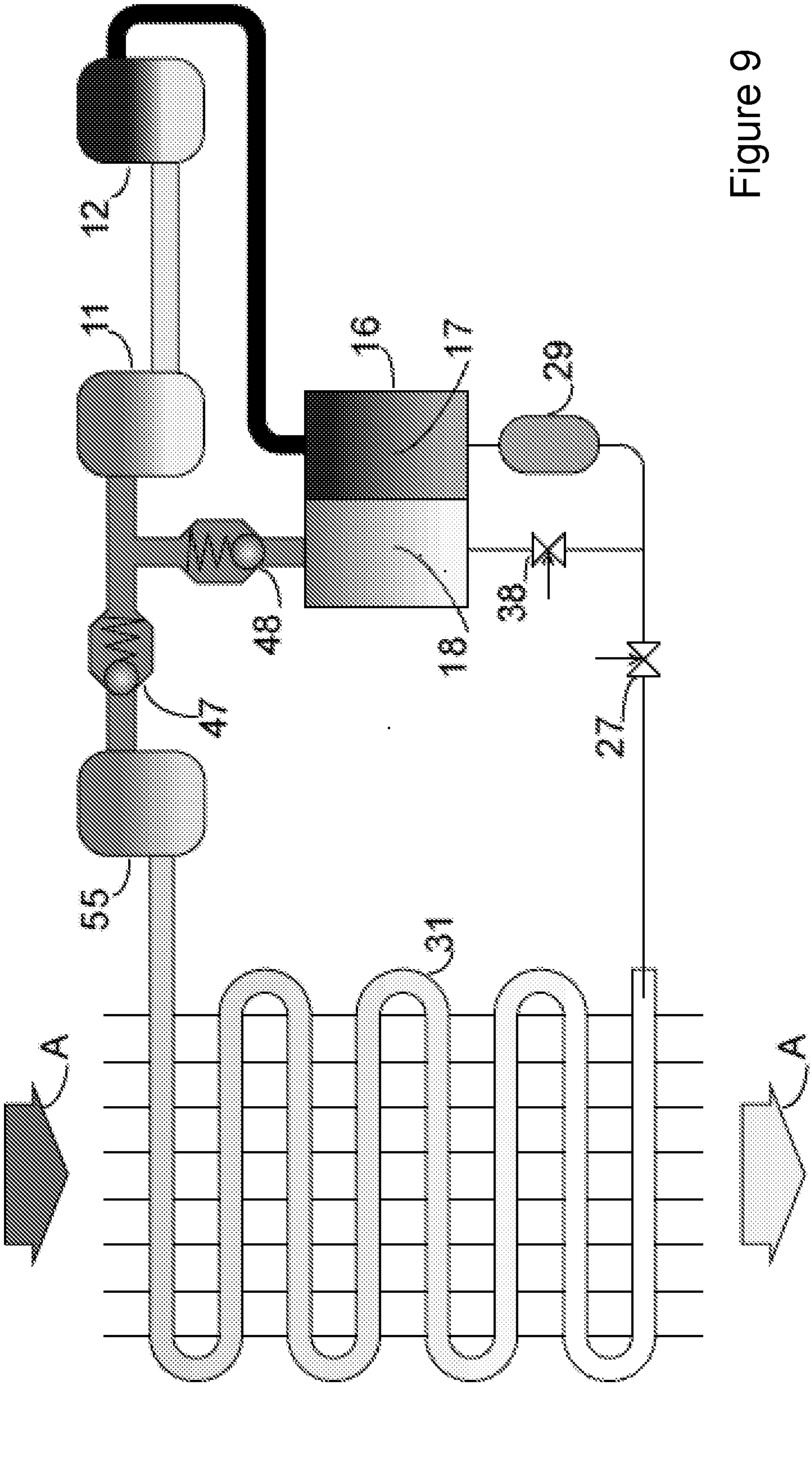

Figure 9

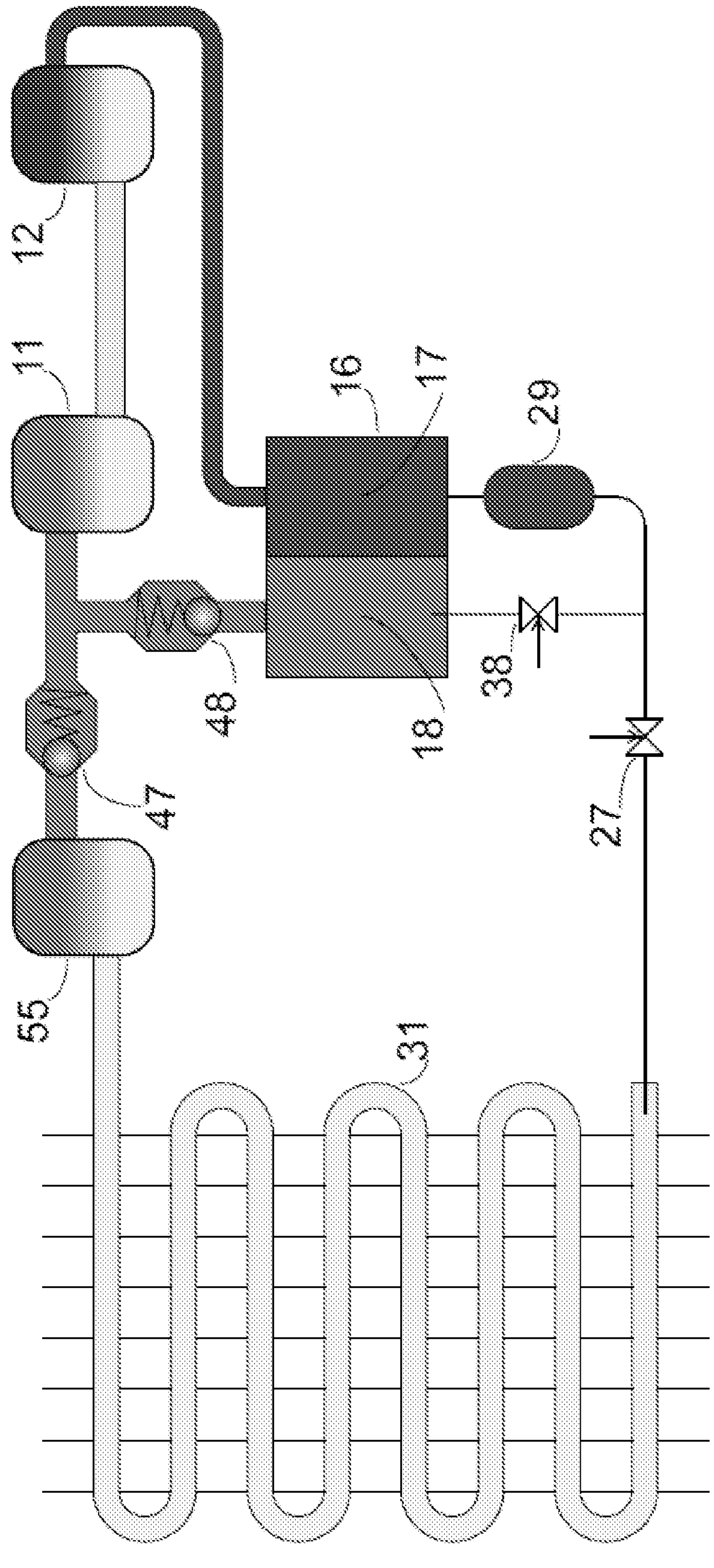

Figure 10

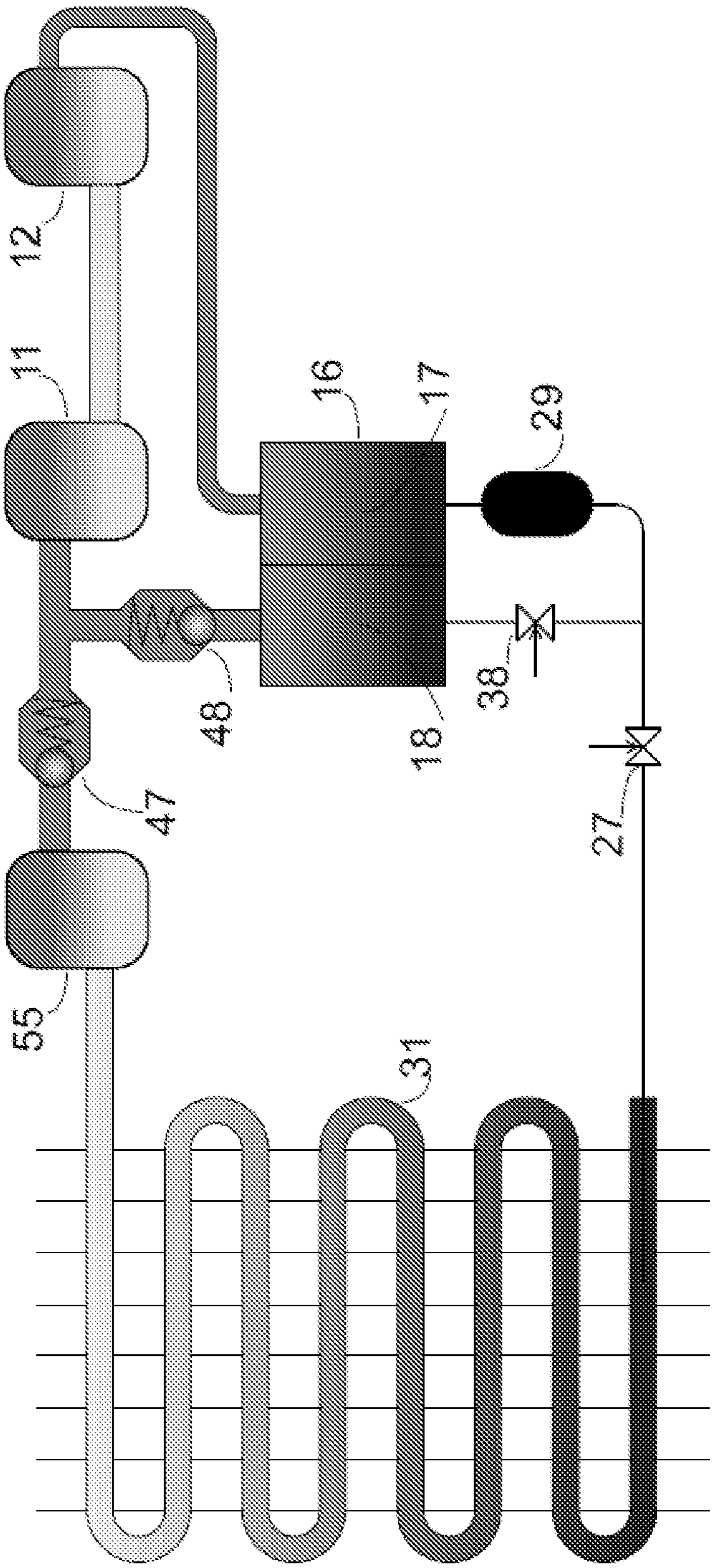

Figure 11

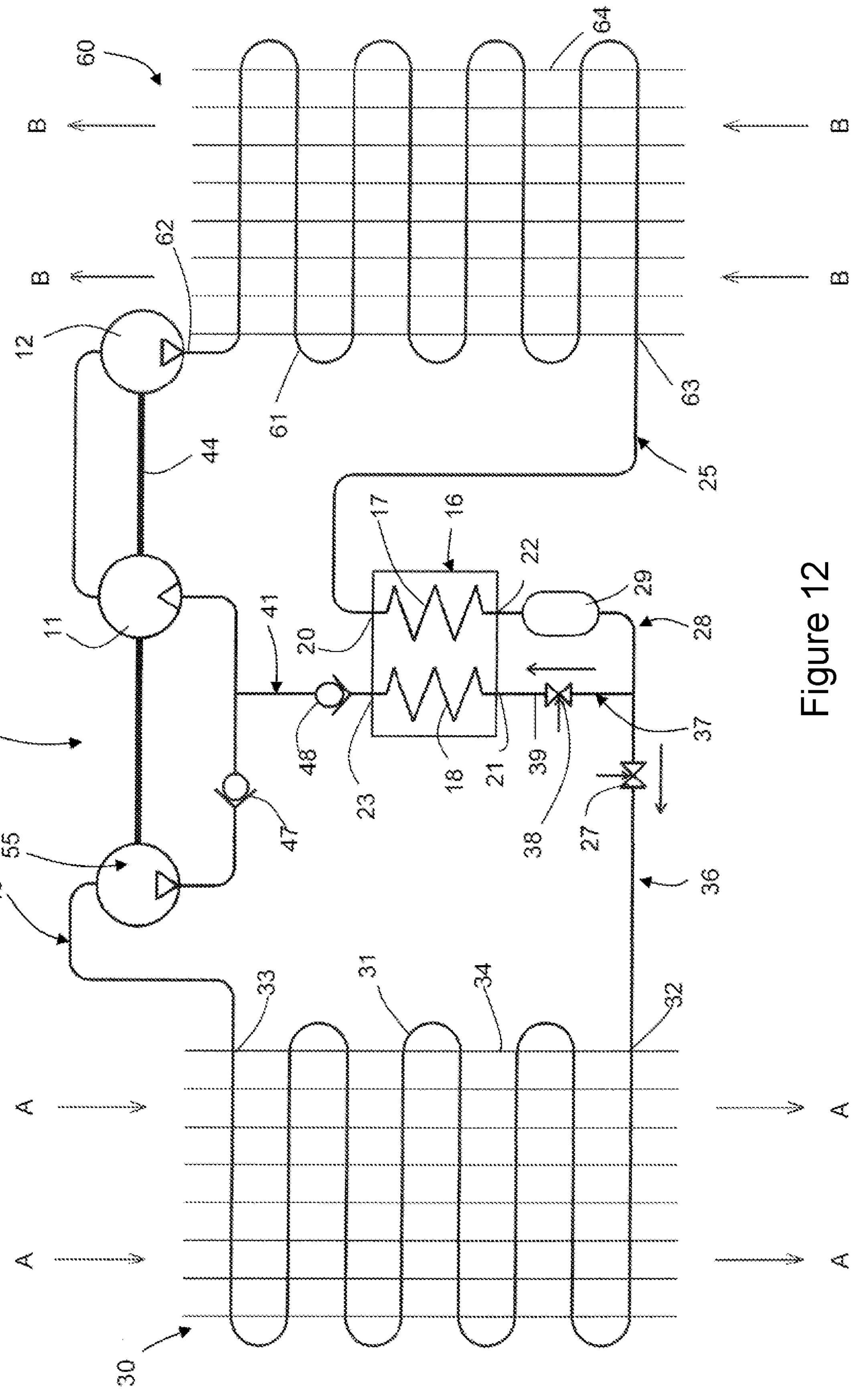
60
64
B
B
B
B
62
12
61
63
44
25
17
16
22
29
11
41
20
28
59
48
23
18
21
39
37
47
38
27
36
55
40
33
31
34
32
A
A
A
A
30

Figure 12

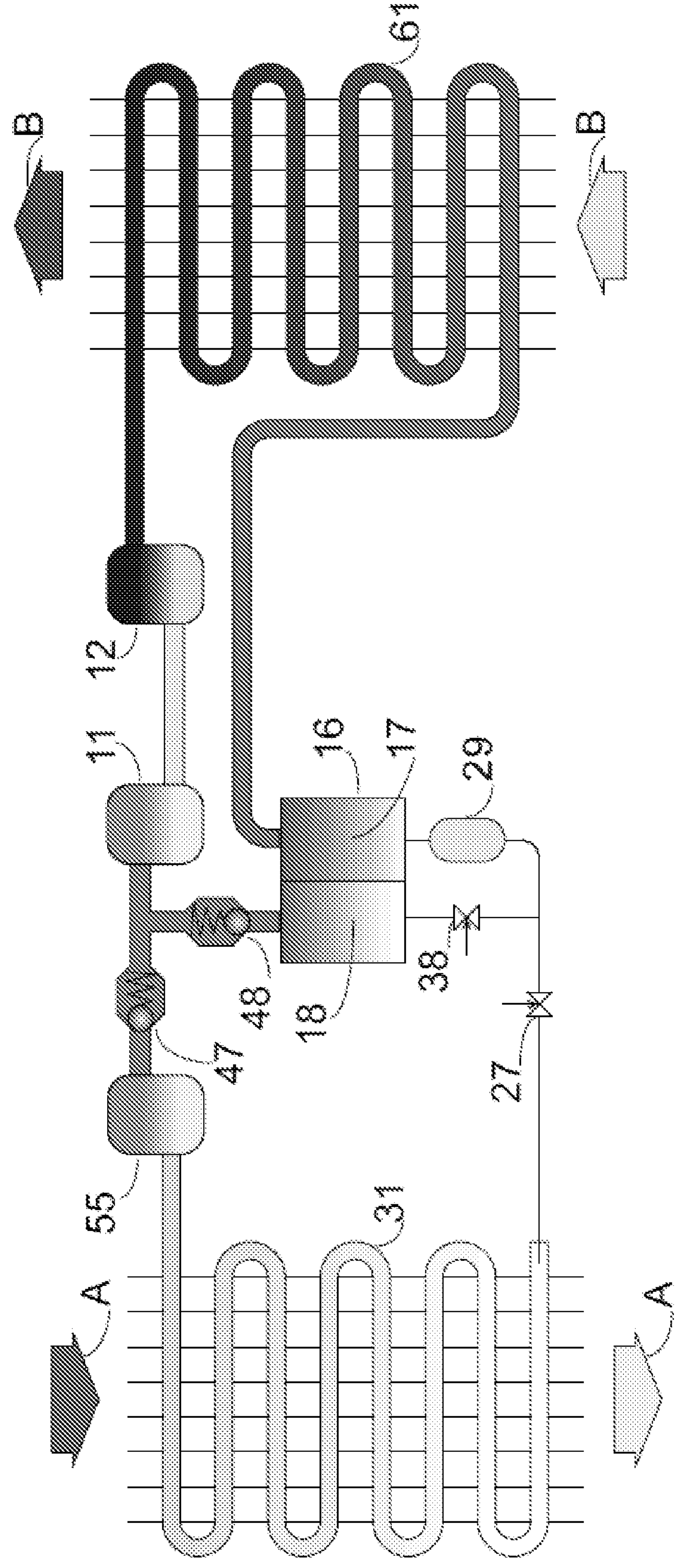

Figure 13

14/14

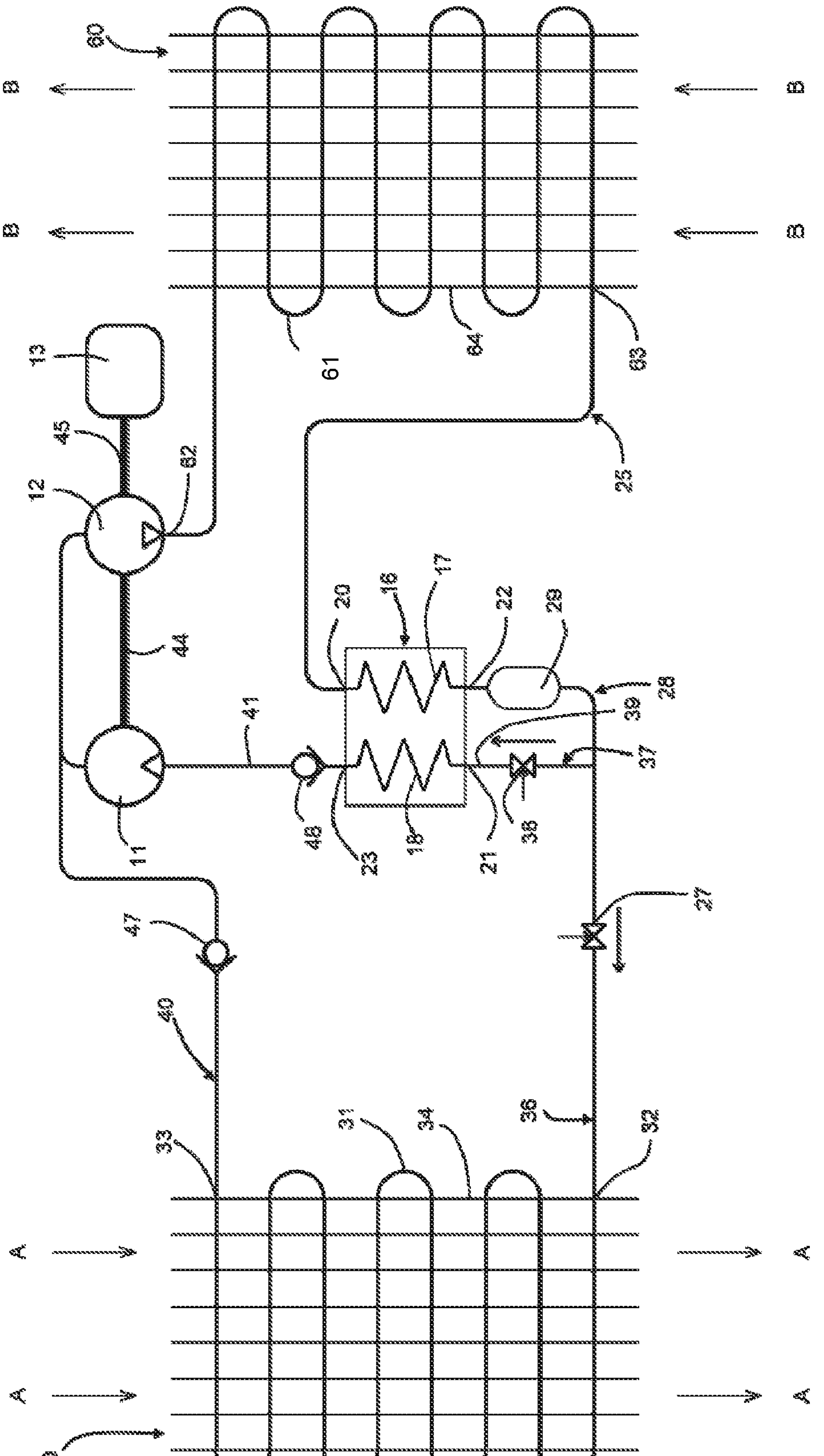

Figure 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2015/052304

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01K25/08 F25B27/00 F25B30/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F01K F25B

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/075970 A1 (BENSON DWAYNE M [US]) 20 March 2014 (2014-03-20)	1-6, 8-11, 16-24, 26-30, 32-34
Y	paragraphs [0008] - [0126]; figure 1	1,14,19
A		7,15,25

X	WO 2011/100974 A1 (AC SUN APS [DK]; MINDS GUNNAR [DK]; MINDS SOEREN [DK]) 25 August 2011 (2011-08-25) pages 1-17; claim 17; figures 3,4	1,3, 9-13, 16-19, 21, 28-31, 33,34

X	WO 2011/043761 A1 (IANNELLO VICTOR [US]) 14 April 2011 (2011-04-14)	1,19
Y	figure 2	1,14,19

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 November 2015	02/12/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Lepers, Joachim

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2015/052304

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014075970 A1	20-03-2014	NONE	
WO 2011100974 A1	25-08-2011	AU 2011217609 A1	04-10-2012
		CN 103229005 A	31-07-2013
		EP 2536983 A1	26-12-2012
		JP 2013519827 A	30-05-2013
		KR 20120135245 A	12-12-2012
		US 2013014529 A1	17-01-2013
		WO 2011100974 A1	25-08-2011
WO 2011043761 A1	14-04-2011	NONE	