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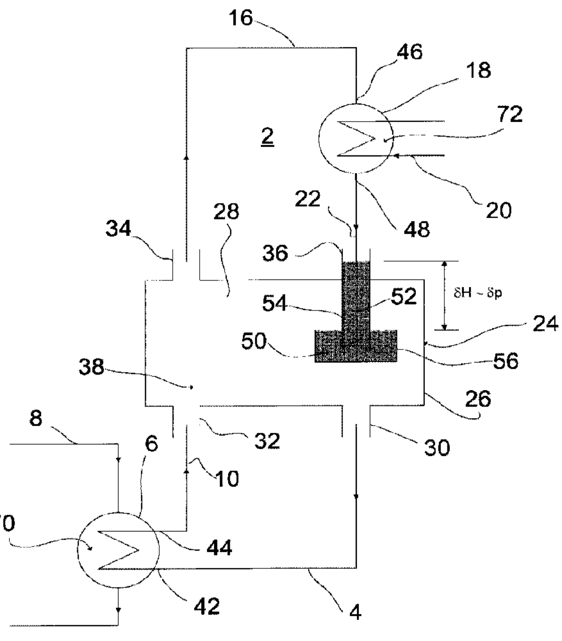

(57) **Abrégé/Abstract:**
A passive two-phase cooling circuit includes a vaporizer and a condenser for a coolant conducted in the cooling circuit. A vaporizer supply line and a vaporizer discharge line are connected to the vaporizer, and a condenser supply line and a condenser discharge line are connected to the condenser. The cooling circuit has a simple and cost- effective structure which reduces or even completely prevents pressure shocks during operation by connecting the vaporizer supply line, the vaporizer discharge line, the condenser supply line and the condenser discharge line to a common damping container. A liquid column forms in the condenser discharge line during the operation of the cooling circuit and the column assumes the function of a liquid-tight seal and of a fluid-dynamic vibration damper.

Abstract

A passive two-phase cooling circuit includes a vaporizer and a condenser for a coolant conducted in the cooling circuit. A vaporizer supply line and a vaporizer discharge line are connected to the vaporizer, and a condenser supply line and a condenser discharge line are connected to the condenser. The cooling circuit has a simple and cost-effective structure which reduces or even completely prevents pressure shocks during operation by connecting the vaporizer supply line, the vaporizer discharge line, the condenser supply line and the condenser discharge line to a common damping container. A liquid column forms in the condenser discharge line during the operation of the cooling circuit and the column assumes the function of a liquid-tight seal and of a fluid-dynamic vibration damper.

Date Reçue/Date Received 2021-06-17

PASSIVE TWO-PHASE COOLING CIRCUIT

Description

Two-phase heat transportation systems, in which the coolant (also referred to as refrigerant) conducted in a circuit undergoes a phase transition from the liquid to gaseous phase and back again, allow high rates of heat transportation when driving temperature differences are low, by comparison with single-phase circuits. However, two-phase systems have much more freedom and therefore are more difficult to control than single-phase systems. This applies in particular to passive systems which manage without active means for influencing flow, such as electric pumps or the like, and in which the transportation of the coolant is in fact brought about only by the differences in temperature prevailing between the associated heat source and heat sink. In particular, irregular pressure fluctuations and pressure shocks, especially condensation-induced pressure surges, in the pipe system present a significant problem, since extreme mechanical stresses can occur in this context. In the worst case scenario, these can lead to the destruction of the system.

The invention addresses the problem of developing a cooling circuit of the type mentioned at the outset in such a way that, in the case of a system of a design which has been kept simple and cost-effective, pressure shocks during operation are reduced or even completely prevented.

An essential component of the apparatus is a damping container, which is also referred to as a decoupling container, having a volume which is to be adapted for specific designs and comprising at least four connections for the pipes of the cooling circuit leading to the vaporiser and to the condenser, and the pipes leading away therefrom. In addition, a tubular component is attached to the connection for the condenser return line which allows the formation of a liquid column. Said liquid column calms the flow in

Date Reçue/Date Received 2021-09-09

transient regions in which it acts as a hydrodynamic vibration damper. In addition, by means of the liquid column, pressure is reduced at the output of the condenser, resulting in an increase in the driving pressure difference in the condenser and thus in an increased mass flow rate.

In summary, the pressure shocks feared up to now in passive two-phase systems can be reduced or even completely prevented by means of the proposed apparatus, which functions as a fluid-dynamic vibration damper. Furthermore, by means of the altered pressure ratios in the circuit, a directed flow can be induced or stabilised (minimising or eliminating secondary return flows), the driving pressure difference in the condenser can be increased, the mass flow rate establishing the heat transportation can be increased, and thus, as a result, a significant performance increase can be achieved.

In other words, the proposed modification of a two-phase cooling circuit by means of passive stabilisation and increased performance brings about much more robust operation and thus increased practicability by comparison with previous systems. By means of the increased power density of the two-phase system, large amounts of heat can be passively discharged when driving temperature differences are low, which cannot be achieved in single-phase systems.

For example, in the nuclear sector, potential applications include discharging heat from wet storage facilities, cooling components (for example in pumps, diesel generator sets, transformers), cooling containments and cooling spaces having an electrically-induced thermal load. Various applications in the non-nuclear sector are of course also possible.

Advantageously, the liquid-tight seal is arranged in the internal space of the damping container, in particular as an integral component thereof or as a component which is pre-mounted therein, and this makes the mounting of the whole system easier.

In a first advantageous variant, the liquid-tight seal, which is also referred to as a siphon, comprises a U, S or J-shaped pipe portion, as is common for example in the field of household installations.

In a second advantageous variant, the liquid-tight seal is achieved in that a pipe or pipe end is immersed in a container or a vessel which laterally surrounds said pipe or pipe end and is open towards the internal space of the damping container so that it is possible to form a liquid column.

In a preferred embodiment, the vaporiser supply line and the vaporiser discharge line feed into the base region of the damping container, more specifically preferably at a distance from one another. In this way, it is ensured that firstly, the mixture of liquid and vaporised coolant flowing in through the vaporiser discharge line can separate in the damping container, and that secondly, the liquid coolant collecting in the base region can flow off into the vaporiser supply line in a simple and unimpeded manner.

By contrast, the condenser supply line preferably feeds into the cover region of the damping container so that the vapour collecting above the liquid coolant can flow into said line in a simple and unimpeded manner.

In order to support the natural circulation in the cooling circuit, the damping container is preferably arranged below the condenser, wherein the condenser discharge line – possibly apart from the portion containing the liquid-tight seal - is formed at least predominantly as a downpipe.

The advantages achieved by means of the invention consist in particular in the fact that, by decoupling the circuits from the vaporiser and the condenser and by producing a fluid-dynamic vibration damper, regulating measures are achieved in a passive system in order to establish a stable and directed flow in the vaporiser and condenser.

One embodiment of the invention will be described in greater detail below with reference to the drawings, which in each case are in a very simplified and schematic form:

Fig. 1 shows a passive two-phase cooling circuit according to the prior art,

Fig. 2 shows a passive two-phase cooling circuit according to the invention, and

Fig. 3 shows an alternative variant to a detail from Fig. 2.

Like parts or parts having like effects are provided with the same reference numerals in all the drawings.

Fig. 1 is a schematic overview of a conventional cooling circuit 2, as used in various technical applications which relate to transporting away excess heat from heated regions of facilities. The directions of flow of the fluids in question are illustrated in each case by flow arrows.

A coolant conducted in a circuit firstly enters a vaporiser 6 in liquid form via a vaporiser supply line 4 (also referred to as a vaporiser intake or feed line). The vaporiser 6 is in the form of a heat exchanger which is heated by means of a thermally coupled heat source 70, which is shown here purely by way of example in the form of a heating pipe 8 conducting a heating medium. By means of a transfer of heat from the heat source 70, the coolant is vaporised at least in part in the vaporiser 6. The coolant vapour produced in this way leaves the vaporiser 6 via a vaporiser discharge line 10 (also referred to as a vaporiser return line or vapour line).

Further downstream, the coolant vapour enters a condenser 18 via a condenser supply line 16 (also referred to as a condenser intake). The condenser 18 is in the form of a heat exchanger which is thermally coupled to a heat sink 72, which is shown here purely by way of example in the form of a cooling pipe 20 conducting a cooling medium. By transferring heat to the heat sink 72, the coolant vapour is condensed in the condenser 18. The coolant which is liquefied once again in this way leaves the condenser 18 via a condenser discharge line 22 (also referred to as a condenser return line), which transitions into the vaporiser supply line 4 further downstream so that the circuit starts again there.

In the case of a cooling circuit having forced flow, a pump 14 for transporting the coolant is connected between the vaporiser discharge line 10 and the condenser supply line 16.

For various applications, however, the cooling circuit 2 is preferably in the form of a passive circuit which manages without active components, in particular without pumps. In this case, the vaporiser discharge line 10 transitions directly into the condenser supply line 16. In this case, the circulation of the coolant is brought about according to the principle of natural circulation by means of the difference in temperature between the heat source 70 and the heat sink 72. For this purpose, the components in question are arranged at a suitable geodetic height relative to one another and are suitable for measuring the respective pipe cross sections etc. The boiling temperature of the coolant is determined in a suitable manner according to the combination of temperature and pressure ratios in the cooling circuit 2 so that the desired vaporisation in the vaporiser 6 and the condensation in the condenser 18 actually take place. Due to the phase changes in the coolant from the liquid to gaseous phase and back again, the circuit is referred to as a two-phase cooling circuit.

Two-phase heat transportation systems allow high rates of heat transportation when driving temperature differences are low. However, pressure shocks or condensation shocks present a significant problem, since extreme mechanical stresses can occur. In the worst case scenario, these can lead to the destruction of the system.

Due to the transient and sometimes chaotic processes in the flow-conducting components, strong fluctuations or vibrations can in particular occur in the system, and therefore vapour-conducting flow regions are shifted into regions with cooler wall temperatures. Then, in some circumstances, the vapour condenses suddenly, thus leading to the above-mentioned condensation shocks.

This can be understood roughly as follows: When a vapour bubble forms in a pipeline of the vaporiser, a strong cooling of the environment takes place. A cyclic cooling of the pipe wall is of particular interest. This means that the wall needs some time to warm up again and reach the required overheating. Strong fluctuations are thus present locally, which vibrate at a specific frequency. Since different boiling ranges are present in the vaporiser pipe, which vibrate at difference frequencies, even in the case of an overall stationary state, a transient state still arises locally. However, since the local boiling conditions in passive systems are still responsible for the propulsion of the flow, there are always flow fluctuations. In the worst case scenario, resonance occurs locally or globally, and the entire system falls into a very disadvantageous state (possibly with considerably reduced heat discharge).

In addition, there is also the following disadvantage: Depending on the level on which the heat sink is located, the condensate may be super-cooled in the condenser. The super-cooled liquid must first be reheated to boiling temperature in the vaporiser. However, since single-phase heat transfer is considerably worse than two-phase heat transfer, the potential of the vaporiser is utilised to only an insufficient extent.

Such phenomena are reduced or even completely prevented according to the invention by means of the apparatus proposed in Fig. 2. The following description builds on the description of Fig. 1 and concentrates on the modifications which have now been made to the cooling circuit 2.

An essential element of the modification is the damping container 24, which is integrated in the cooling circuit 2 and acts as a fluid-dynamic vibration damper in conjunction with a liquid column, which damping container can also be referred to as a decoupling container with respect to the function thereof of decoupling the vaporiser and condenser circuits (see below). The damping container 24 comprises an internal space 28 which is sealed in a pressure-tight manner with respect to the environment on all sides by a surrounding wall 26, the volume of said internal space being sufficiently large with regard to the main tasks assigned thereto of damping vibrations and conducting media. Furthermore, four connections 30, 32, 34, 36 which have different functions to one another are provided, which are connected to the pipe system of the cooling circuit 2 in a specific manner. During the operation of the cooling circuit 2, liquid coolant and coolant vapour collect in the internal space 28 of the damping container 24, the liquid phase collecting at the bottom towards the base region 38 as a result of the gravity acting thereon, and the gaseous/vaporous phase collecting above the liquid phase towards the cover region 40.

A first connection 30 is guided through the surrounding wall 26 in the base region 38 of the damping container 24, in particular directly in the base. Said connection is connected to the vaporiser supply line 4 leading to the vaporiser inlet 42, so that liquid coolant collecting in the base region 38 during operation flows via the connection 30 and the vaporiser supply line 4 to the vaporiser 6, where the vaporisation of the coolant takes place.

The vaporiser discharge line 10 coming from the vaporiser outlet 44 is connected to a second connection 32, which is likewise guided through the surrounding wall 26 in the base region 38 of the damping container 24, in particular directly in the base, or optionally slightly higher. In general, the coolant in the vaporiser 6 is not vaporised completely, but rather is vaporised only in part, and the resulting mixture of liquid coolant and coolant vapour is thus conducted via the vaporiser discharge line 10 and the connection 32 into the internal space 28 of the damping container 24, where a phase separation takes place as described previously.

A third connection 34 is guided through the surrounding wall 26 in the cover region 40 of the damping container 24, in particular directly in the cover. The condenser supply line 16 leading to the condenser inlet 46 is connected to said third connection, so that coolant vapour collecting in the cover region 40 flows via the connection 34 and the vaporiser supply line 16 to the condenser 18, where the condensation of the coolant vapour takes place.

Lastly, a fourth connection 36 is guided through the surrounding wall 26 in the cover region 40 of the damping container 24, in particular directly in the cover. The condenser discharge line 22 coming from the condenser outlet 48 is connected to said fourth connection, so that the coolant which is liquefied in the condenser 18 flows into the damping container 24 via the condenser discharge line 22 and the connection 36.

In the case of the three connections 30, 32, 34 mentioned first, the connected pipelines 4, 10, 16 feed directly into the internal space of the damping container 24 to the extent that, in the case of normal operational flow ratios, it is possible to compensate the pressure between the internal space 28 and said pipelines 4, 10, 16. By contrast, the fourth connection 36 is created in such a way that the pipeline which is connected thereto, namely the condenser discharge line 22, feeds into the internal space 28 of the damping container 24, thus forming a liquid-tight seal 50. A liquid-tight seal 50 of this type is also referred to as a siphon or trap. By means of the liquid column 52 of liquid coolant forming during the operation of the cooling circuit 2, the passage of gases is prevented or in any case made more difficult, and therefore a pressure separation is achieved between the internal space 28 and the condenser discharge line 22. The height δH of the resulting liquid column 52 correlates in this case to the prevailing pressure difference δp.

The liquid-tight seal 50 can in principle be arranged outside the damping container 24. Expediently, however, said seal is produced in a pipe portion in the internal space 28 of the damping container 24, and can take any form which is expedient for the function. For example, as shown in Fig. 2, said seal can comprise a pipe end 54, which is immersed from above in a container 56 which is open at the top. Alternatively or additionally, the known U, S or J-shaped pipe portions 58 or embodiments having equivalent functions can be used, as shown in Fig. 3 by way of example, with reference to a J-bend.

By means of the liquid column 52 of the siphon, the return flow of the vapour and the damping of the system are carried out. This means that the liquid column 52 must be produced according to the expected system instabilities. In Fig. 2, the upwardly pointing opening of the surrounding container 56 has a considerably greater cross-sectional area than the immersed pipe 54. This means that a small difference in height in the container 56 leads to a considerably greater difference in height in the pipe 54 (corresponding to the area ratios). Since the overall height difference δH correlates with the pressure difference δp, the pressure fluctuations in the system are counteracted. The installation height of the siphon must be determined according to the overall spread of the system. This means that, in the case of low thermal outputs, the liquid phase is predominantly located in the vaporiser region, with the container being virtually empty. In the case of high thermal outputs, a relatively large amount of the liquid phase is located in the container (due to the high proportion of vapour in the vaporiser). The components are to be laid out on this basis.

In order to support the natural circulation in the cooling circuit 2, the vaporiser 6, the condenser 18 and the damping container 24 are located at a suitable geodetic height relative to one another. In particular, the damping container 24 is preferably arranged below the condenser 18, so that the condenser discharge line 22 leading from the condenser 18 to the damping container 24 is substantially in the form of a downpipe. From a purely hydrostatic perspective, it is further considered to be advantageous to arrange the vaporiser 6 below the damping container 24. As a result, the vaporiser discharge line 10 is preferably a standpipe, and the vaporiser supply line 4 is preferably a downpipe. However, since this system is a fluid-dynamic system which is additionally a two-phase system, it is possible that, in practice, a different arrangement would prove beneficial.

In summary, in the case of the cooling circuit 2 according to Fig. 2, both the pipe loop leading from the vaporiser 6 to the condenser 18 and the pipe loop leading from the condenser 18 to the vaporiser 6 are thus guided through the common damping container 24. The liquid column 52 in the damping container 24 together with the compensation volume created by the internal space 28 decouples the circuits and calms the flow in transient regions in which it acts as a hydrodynamic vibration damper. In addition, by means of the liquid column 52, pressure is reduced on the outlet side in the condenser 18, resulting in an increase in the driving pressure difference in the condenser 18 and thus in an increased mass flow rate in the cooling circuit 2.

Another advantage of the damping container 24 is that the condensate is preheated. Since a (relative) vapour content of less than one is present at the vaporiser outlet 44, some of the saturated liquid flows through the damping container 24 back to the vaporiser inlet 42. In this case, the optionally super-cooled condensate is mixed with the saturated liquid. As a result, the regions of the single-phase heat transfer in the vaporiser 6 are minimised, and the overall process is improved (thermodynamic optimisation).

The apparatus shown in Fig. 2 and 3 acts both to improve the efficiency of the heat discharge and also to reduce condensation shocks in the case of a passive two-phase cycle.

List of reference numerals

2	cooling circuit
4	vaporiser supply line
6	vaporiser
8	heating pipe
10	vaporiser discharge line
14	pump
16	condenser supply line
18	condenser
20	cooling pipe
22	condenser discharge line
24	damping container
26	surrounding wall
28	internal space
30	first connection
32	second connection
34	third connection
36	fourth connection
38	base region
40	cover region
42	vaporiser inlet
44	vaporiser outlet
46	condenser inlet
48	condenser outlet
50	liquid-tight seal
52	liquid column
54	pipe end
56	container
58	pipe portion
70	heat source
72	heat sink

Claims

1. Passive two-phase cooling circuit comprising a vaporiser and a condenser for a coolant conducted in the cooling circuit, a vaporiser supply line and a vaporiser discharge line being connected to the vaporiser, and a condenser supply line and a condenser discharge line being connected to the condenser, the vaporiser supply line, the vaporiser discharge line, the condenser supply line, and the condenser discharge line further being connected to a common damping container, a liquid column of liquid coolant forming in the condenser discharge line during operation of the cooling circuit, which liquid column assumes the function of a liquid-tight seal and the function of a fluid-dynamic vibration damper, characterised in that the condenser discharge line feeds into a cover region of the damping container and comprises a pipe portion projecting into an internal space of the damping container, in which the liquid-tight seal is produced.

2. Cooling circuit according to claim 1, wherein the liquid-tight seal comprises one of a U, S and J-shaped pipe portion.

3. Cooling circuit according to claim 1 or claim 2, wherein the liquid-tight seal comprises a pipe end which is immersed in a container which is open at the top.

4. Cooling circuit according to any one of claims 1 to 3, wherein the vaporiser supply line and the vaporiser discharge line feed into a base region of the damping container.

5. Cooling circuit according to any one of claims 1 to 4, wherein the damping container is arranged below the condenser, and wherein the condenser discharge line is predominantly in the form of a downpipe.

Date Reçue/Date Received 2021-06-17

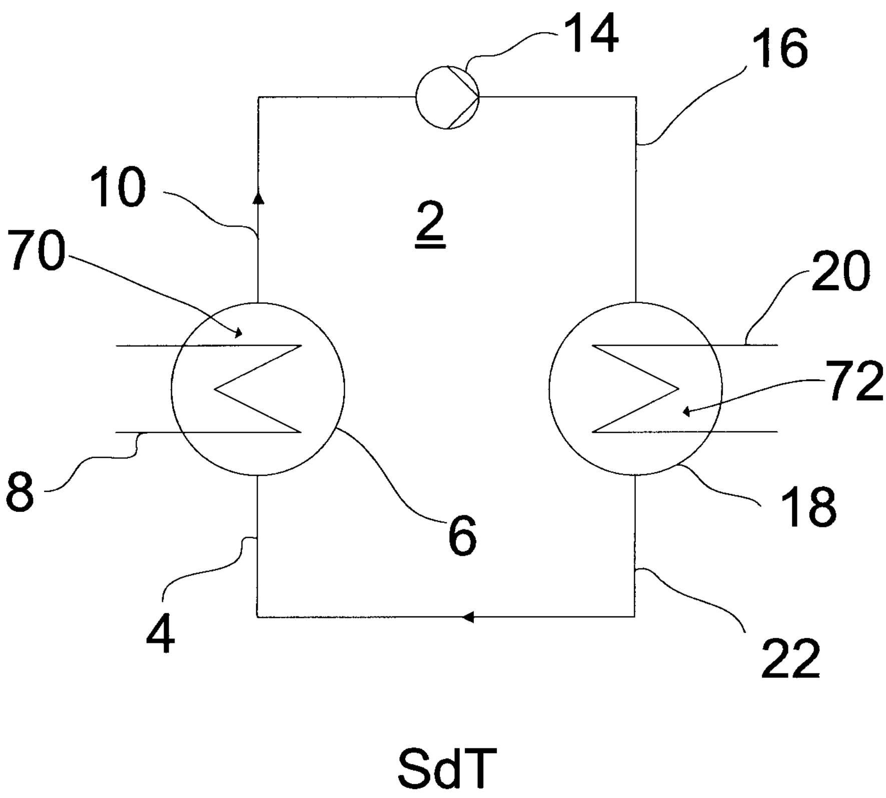

Fig. 1

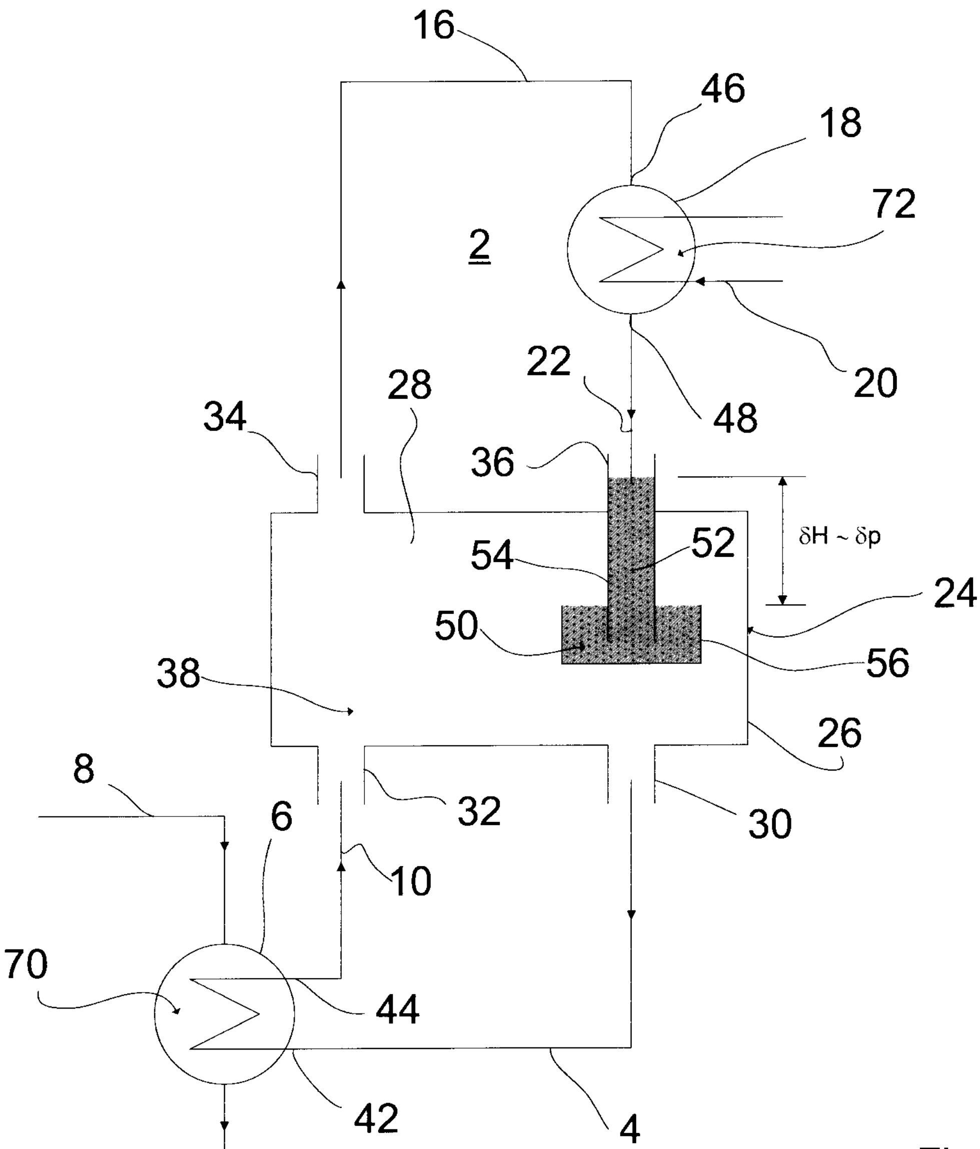
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Fig. 2

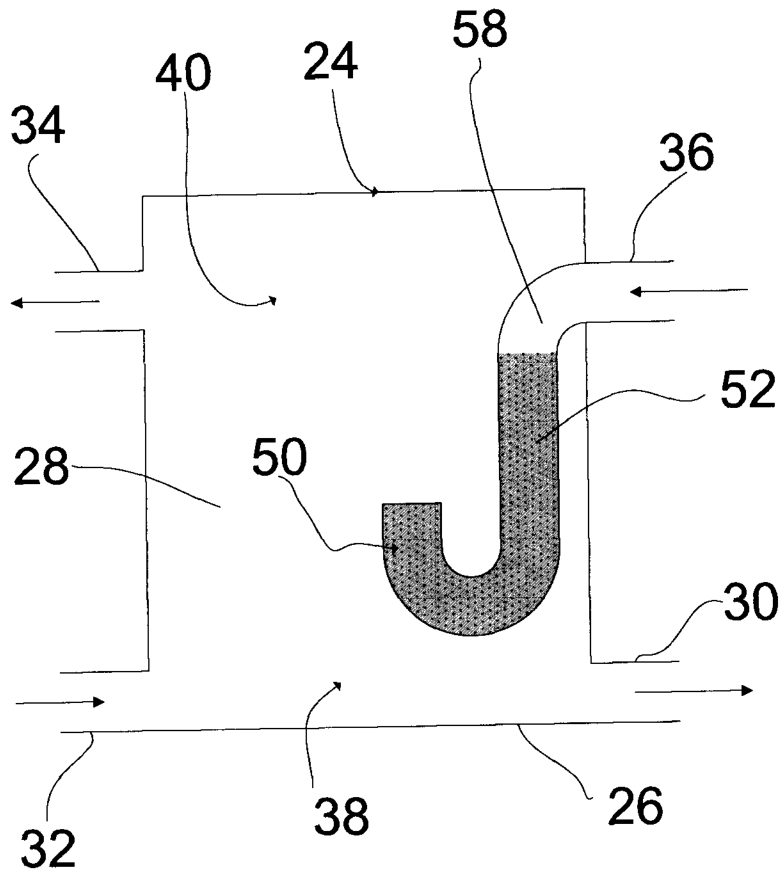
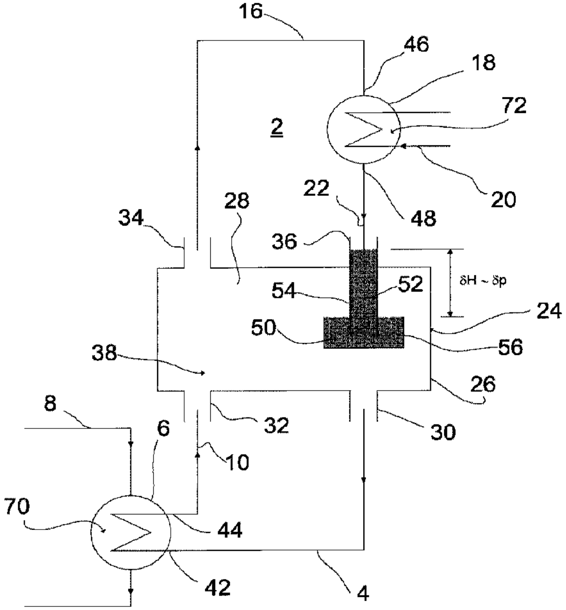


Fig. 3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