



(11) **EP 1 832 828 A1**

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 158(3) EPC

(43) Date of publication:
12.09.2007 Bulletin 2007/37

(51) Int Cl.:
F28D 15/02 (2006.01) F25D 9/00 (2006.01)

(21) Application number: **05811624.5**

(86) International application number:
PCT/JP2005/021956

(22) Date of filing: **30.11.2005**

(87) International publication number:
WO 2006/059622 (08.06.2006 Gazette 2006/23)

(84) Designated Contracting States:
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR
HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI
SK TR**

(30) Priority: **03.12.2004 JP 2004350757**

(71) Applicants:
• **Da Vinci Co., Ltd.**
Yamatotakada-shi, Nara 635-0071 (JP)
• **The University of Tokyo**
Bunkyo-Ku,
Tokyo 113-0033 (JP)

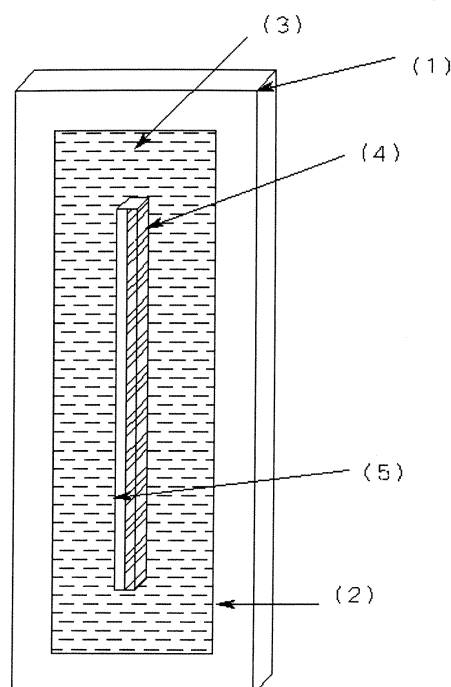
(72) Inventors:
• **NAKASUGA, Shinichi,**
The university of Tokyo
Tokyo,
113-0033 (JP)
• **SAHARA, Hironori,**
The university of Tokyo
Tokyo,
113-0033 (JP)
• **HIGASHI, Kenji**
6350071 (JP)

(74) Representative: **Reitstötter - Kinzebach**
Patentanwälte
Sternwartstrasse 4
81679 München (DE)

(54) **MAGNETIC CONVECTION HEAT CIRCULATION PUMP**

(57) A magnetic convection heat circulation pump, wherein magnets are disposed inside a magnetic field flow passage for passing a magnetic fluid therein or on a part of the inner wall surface of a circulation flow passage in a magnetic pump thermally joined to a heat receiving part. The magnetic fluid is driven since a magnetic force is directly applied to the magnetic fluid and a large temperature gradient is produced between the heat receiving part and the magnetic pump due to a difference between a heat quantity transferred from the heat receiving part indirectly to the magnetic pump and the heat quantity of the magnetic fluid led into the magnetic pump.

Fig. 1



EP 1 832 828 A1

Description

TECHNICAL FIELD

[0001] The present invention relates to a device for transferring heat energy. More particularly, it relates to a magnetic convection heat circulation pump which utilizes a magnetic fluid exhibiting temperature-dependent saturation magnetization.

[0002] Heat transfer devices utilizing magnetic convection of a magnetic fluid exhibiting temperature-dependent saturation magnetization have long been known, but they have not been put into commercial practice for several reasons including the difficulty of producing a magnetic fluid having uniform distribution of finely divided ferromagnetic particles of little or no residual magnetism.

[0003] Attempts have been made to obviate the above problems in recent years. For example, JP 10/231814A discloses a fluid flow control device utilizing a paramagnetic gas exhibiting temperature-dependent saturation magnetization, while JP 3/102804A discloses a heat transfer device utilizing a magnetic fluid exhibiting temperature-dependent saturation magnetization. In these devices, a heater is provided in the vicinity of magnetic field to create a temperature gradient in a fluid flow path by heating externally.

[0004] However, the devices having external heating means have only limited uses and are not suitable for cooling an object.

[0005] A system for moving a magnetic fluid through a fluid flow path is known. The system comprises a plurality of electromagnets disposed spaced apart in row alongside the fluid flow path and a controller for sequentially energizing the electromagnets. However, the system is complicated and expensive because of the controller and requisite wiring.

DISCLOSURE OF THE INVENTION

[0006] It is an object of the present invention to provide a magnetic convection heat circulation pump which utilizes a magnetic fluid exhibiting temperature-dependent saturation magnetization wherein the magnetic fluid is circulated in a flow path without need for external power source, and wherein a large temperature gradient of the magnetic fluid is created in the flow circuit to thereby generate a gradient of the magnitude of saturation magnetization of the magnetic fluid under the influence of a magnetic field.

[0007] The above object is accomplished by the magnetic convection heat circulation pump according to the present invention which comprises a heat receiving section, a heat discharging section, and a fluid circulation path for circulating a magnetic fluid between said heat receiving section and said heat discharging section wherein at least a magnet is disposed within said fluid circulation path or part thereof in said heat receiving sec-

tion so that a magnetic convection is continuously created in said magnetic fluid due to a temperature gradient in said fluid circulation path.

[0008] In the magnetic convection heat circulation pump of the present invention, the magnetic fluid in the fluid circulation path receives heat in said heat receiving section to decrease the magnitude of saturation magnetization in response to the magnetic field applied to the fluid circulation path and tends to displace in the fluid circulation path toward the heat discharging section creating magnetic convection. Therefore, the pump is simple in structure, operates as far as a temperature differential is present between the heat receiving and discharging sections, and has an advantage of transferring a large quantity of heat by circulating the magnetic fluid as fast as possible using a large temperature differential.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009]

Fig. 1 is a schematic view of the magnetic convection heat pump of the present invention having a magnet disposed in the fluid circulation path.

Fig. 2 is a schematic view of similar heat circulation pump having a pair of linearly connected magnets.

Fig. 3 is a schematic view of similar heat circulation pump having a pair of magnets arranged in parallel.

Fig. 4 is a schematic view of similar heat circulation pump having a pair of magnets arranged at an angle.

Fig. 5 is a schematic view of similar heat circulation pump having a pair of magnets attached to the legs of an inverted U-shaped ferromagnetic support member.

Figs. 6 and 7 show schematically the magnetic convection heat circulation pump of the present invention having a magnet disposed in the fluid circulation path.

Figs. 8 and 9 show schematically the magnetic convection heat circulating pump of the present invention having a fluid circulation path partly defined by a ring-shaped magnet.

Fig. 10 is a perspective view of the magnetic convection heat circulation pump of the present invention having reduced pump thickness.

Fig. 11 shows schematically the arrangement of magnets supported in a yoke member.

BEST MODE FOR CARRYING OUT THE INVENTION

[0010] According to the present invention, one or more magnets are disposed in the circulation path of a magnetic fluid. Alternatively part of the fluid circulation path may be defined by one or more magnets. Preferably, the magnets are plated with nickel or the like on the surfaces directly contacting the magnetic fluid and the plated surfaces are coated with a surfactant having the same ionic charge as the surfactant used for coating the particulate

ferromagnetic material dispersed in the magnetic fluid. The above treatment allows direct application of the magnetic field to the magnetic fluid with reduced flow resistance.

[0011] Preferably, a ferromagnetic material having strongly temperature-dependent saturation magnetization such as a ferrite comprising manganese and zinc is employed as the particulate ferromagnetic material of the magnetic fluid. The particulate ferromagnetic material has an average particle size less than about 10 nm, preferably less than 6 nm, most preferably about 1 nm. The selection of suitable ferromagnetic material and optimum particle size contributes to minimum residual magnetization and most efficient heat circulation by the pump.

[0012] It is also preferable to construct the heat receiving section and the magnetic pump section from different materials having mutually different heat conductivity values in association with a common magnetic flow path.

[0013] Now a few exemplifying embodiments of the present invention will be described with reference to Figs. 1-6 of the accompanying drawings.

[0014] The embodiment shown in Fig. 1 comprises a circulation path (3) for circulating a magnetic fluid between a heat receiving section (1) and a heat discharging section (2), and a magnet assembly comprising a pair of elongated magnets (4,5) centrally disposed in the circulation path (3). When the magnetic fluid receives heat in the heat receiving section (1), a temperature gradient is created between the magnetic fluid retained in the heat receiving section (1) and the heat discharging section (2) and the magnetic fluid retained in the heat receiving section (1) having decreased magnetization is expelled by the magnetic fluid retained in the heat discharging section (2) having higher magnetization than the fluid retained in the heat receiving section (1) under the influence of the magnetic field of the elongated magnet centrally disposed in the circulation path (3). Thus heat transfer occurs from the heat receiving section (1) to the heat discharging section (2) by the magnetic convection.

[0015] In the embodiment shown in Fig. 1, the magnetic force is directly exerted to the magnetic fluid not only resulting in efficient circulation of heat but also remarkably decreasing the effect of leaked magnetic flux to various electronic devices when used for discharging heat therefrom.

[0016] The magnetic fluid used in the present invention comprises a dispersion of particulate ferromagnetic material in a suitable dispersion medium. The particulate ferromagnetic material preferably has an average particle size less than 30nm, more preferably in a range between 1nm and 10nm.

[0017] The ferromagnetic material used in the present invention is preferably comprised of a ferrite compound having highly temperature-dependent saturation magnetization such as a ferrite comprising a divalent transition metal.

[0018] The particles of ferromagnetic material preferably have a coating of an ionic surfactant, i.e. either an-

ionic or cationic surfactant on their surfaces to impart individual particles with repulsing force so that the particles may be stably and uniformly dispersed in a dispersion medium to contribute to decreased effect of residual magnetization and decreased flow resistance in the circulation path.

[0019] Preferably, the magnets disposed in or forming part of the circulation path also have on their surfaces contacting the magnetic fluid a coating of the same ionic surfactant as the coating of the ferromagnetic particles. The coating of ionic surfactant on the surfaces of the magnet also contributes to decreased effect of residual magnetization and decreased flow resistance in the circulation path.

[0020] The efficiency of magnetic convection pump may be remarkably promoted by the use of a ferromagnetic material exhibiting highly temperature-dependent saturation magnetization. In a preferred embodiment, a manganese-zinc ferrite of the formula $1/2 \text{ Zn } 1/2 \text{ Mn Fe}_2\text{O}_4$ is employed. However, other ferrites having comparable temperature-dependent saturation magnetization may be used as well.

[0021] The use of a magnetic ionic liquid as the magnetic fluid is within the scope of the present invention. Typical example of the magnetic ionic liquid is comprised of ferric oxychloride anion and 1-butyl-3-methylimidazolium cation.

[0022] Figs. 2-4 show further embodiments of the magnetic convection circulation pump of the present invention. In the embodiment shown in Fig. 2, a magnet assembly comprises a plurality of magnets (4,4b, 5, 5b) connected in series. The magnet assembly is disposed in the magnetic fluid (3) with the magnet having stronger magnetic force extending toward the heat receiving section. In the embodiment shown in Fig. 3, a pair of magnets are disposed in opposed positions in the circulation path (3). In the embodiments shown in Fig. 4, a pair of magnets are disposed in the circulation path (3) at an angle so that the spacing between the magnet pair is minimum at the ends facing toward the heat receiving side. By creating the strongest magnetic field on the heat receiving side in the circulation path (3) as shown, the magnetic fluid retained in the heat discharging side will be moved to the heat receiving side more easily.

[0023] In the embodiment shown in Fig. 5, a pair of magnets are attached to a support member (10) made of ferromagnetic material. The support member (10) has an inverted U-shape and the pair of magnets are supported by the legs at opposing positions. This configuration contributes to the reduction of leakage of magnetic flux and also to stronger magnetic force between the opposing magnets.

[0024] The embodiment shown in Fig. 6 is provided with three circulation paths (7,8,9). The magnet having opposite poles (4,5) are disposed in the first circulation path (7) in the heat receiving section (1) to create a magnetic flow path (6). The magnet may be disposed any one of three circulation paths and the magnetic flow path

(6) may be created on both sides of the magnet. The magnetic heat pump shown in Fig. 6 operates with fewer volume of the magnetic fluid than the magnetic heat pump shown in Fig. 1.

[0025] In the embodiment shown in Fig. 7, the heat receiving section (1) is separated from the heat discharging section (2). Both section have their own fluid circulation paths which are connected end-to-end in closed loop with connecting tubings made of flexible materials. By connecting two sections with flexible tubings, their relative positions may be changed as desired.

[0026] In the embodiment shown in Fig. 8, the magnetic convection heat pump comprises a pair of magnet rings (4a,5a) which are concentrically connected to the end of associated fluid circulation path as part of connecting conduit (12) between the heat receiving section (1) and the heat discharging section (2). According to this embodiment, the heat receiving and heat discharging sections (1,2) may be constructed by common parts and allows easy connection and disconnection of circulation path at magnetic connection site (11) and facilitates filling and withdrawing the magnetic fluid into and from the fluid circulation path (3).

[0027] The magnet disposed in the fluid circulation path (3) may be secured by any means, for example, movable engagement into a mating groove, glueing and the like.

[0028] The heat receiving section (1) and the heat discharging section (2) are preferably constructed from a material having a high heat conductivity such as copper, aluminum or graphite. More preferably, such a material has low magnetic permeability.

[0029] Now still further embodiments of the magnetic convection heat circulation pump of the present invention will be described making reference to Figs. 9-11. The term "magnetic pump (14) section" as used herein refers to the section in which the magnet (13) placed in the associated magnetic flow path (6) is located. In the embodiment shown in Fig. 9, the end portion of the magnetic flow path (6) on the heat receiving section side is tapered to prevent reverse flow of the magnetic fluid and the magnet (13) and the magnetic flow path (6) extend in part into the heat receiving section (1). Moreover, the heat receiving section (1) and the magnetic pump section (14) each constructed from a mutually different material having different heat conductivity are thermally coupled together.

[0030] In addition, the magnetic flow path (6) and the fluid circulation path (3) in the heat receiving section (1) is connected in fluid flow communication to the heat discharging section (2) by a connecting flexible conduit made of, for example, fluorocarbon resin. In the heat circulation pump as shown in Fig. 9, heat inputted in the heat receiving section (1) is directly transferred to part of the magnetic flow path extending in the heat receiving section (1) but the heat is transferred only indirectly to the magnetic pump section (14).

For furthermore, since the magnetic pump section (14) is

made of a material having a heat conductivity less than the material of the heat receiving section (1), the quantity of heat transferred to the magnetic pump section (14) is not sufficient to raise the temperature of that section as high as the temperature of the heat receiving section (1). This creates a temperature gradient within the area of magnetic flow path (6) and the magnetic fluid retained in the region of magnetic flow path having higher temperature is magnetically expelled by the magnetic fluid retained in the region of magnetic flow path having lower temperature due to the gradient of the magnitude of saturation magnetization. Once this has occurred, cold magnetic fluid will flow into the magnetic pump section (14) from the heat discharging section (2) to begin with the circulation of magnetic fluid through the entire heat circulation path (3). In order to create a temperature gradient sufficient to drive the magnetic fluid by the magnetic force the heat receiving section (1) and the magnetic pump section (14) are constructed, for example, from aluminum or like metallic material and a polymeric material respectively.

[0031] Although not shown in Fig. 9, the direction of magnetization of the magnet 13 may be either in the longitudinal direction or the direction perpendicular thereto. In case of longitudinal magnetization direction, for example, the location where the temperature gradient occurs will be shifted from the point where the magnetic field is strongest to the central part of the magnet where the magnetic field is weakest as the heat input decreases. Accordingly, it is envisaged to have a magnetic convection heat circulation pump for maintaining the temperature of a heat generating parts at constant by using a magnet adapted for such applications.

[0032] Also not shown in the drawings, the fluid circulation path preferably has at least partially on the surfaces contacting the magnetic fluid a coating of either an oil repellent material such as SITOP sold by Asahi Glass or an ionic surfactant of the same type used for coating the particulate ferromagnetic material of the magnetic fluid. For example, a cationic surfactant is used for coating both the circulation path and the particulate ferromagnetic material. The coating of the fluid circulation path contributes to decreased shear stress of the path and also to the prevention of agglomeration of particulate ferromagnetic material.

[0033] Fig. 9 illustrates an embodiment of the magnetic heat pump of the present invention having a magnetic flow path (6) common between the heat receiving section (1) and the magnetic pump section (14). However, the magnetic flow path (6) does not necessarily require to be common when the heat receiving section (1) is thermally couple to the magnetic pump section (14) using a metal having good thermal conductivity.

[0034] In the embodiment shown in Fig. 10, the heat receiving section (1) and the magnetic pump section (14) are constructed from the same material having the same heat conductivity. However, the heat receiving section (1) has an overall thickness greater than that of the mag-

netic pump section (14). Accordingly, the heat receiving section functions as a heat sink and reduces the quantity of heat to be transferred to the magnetic pump section (14) to create a remarkable temperature gradient in the magnetic flow path (6) in a similar manner when the both sections are constructed from different materials having mutually different heat conductivity.

[0035] In the embodiment shown in Fig. 11, a pair of magnets (13) having opposite polarity are supported by a yoke member (15) in diametrically opposing positions to strengthen the magnetic field therebetween. The plane not occupied by the magnets serves as a magnetic flow path (6) and the magnetic fluid can flow thereon without any disturbance. The leakage of magnetic flux may greatly reduced by this structure.

[0036] The magnetic heat pump according to the present invention can convey a large quantity of heat per unit area. The heat pump may be constructed in small sizes suitable for mounting on a variety of electric and electronic instruments. Therefore, it finds use in a cooling system for instruments having a high power consumption density such as CPU, laser diode opticts and other electronic devices.

[0037] The magnetic heat pump according to the present invention operate without need for power supply. Therefore, it finds use in heat dissipation of self-operated instruments, utilization of solar heat energy, and recycling waste heat energy.

[0038] The magnetic heat pump according to the present invention utilizes essentially non-volatile magnetic fluid. Because of this, it may find use in heat transfer in space stations and satellites.

Claims

1. A magnetic convection heat pump comprising a heat receiving section, a heat discharging section, and a circulation path for circulating a magnetic fluid between said heat receiving section and said heat discharging section, wherein at least one magnet member is carried on the inner wall of said circulation path or included in said circulation path.
2. A magnetic convection heat pump comprising a heat receiving section, a magnetic pump section thermally coupled to said heat receiving section, a heat discharging section, and a circulation path for circulating a magnetic fluid, said circulation path connecting said heat receiving section, said magnetic pump section and said heat discharging section in fluid communication, wherein a portion of said circulation path in said magnetic pump section carries or include at least one permanent magnet member to form a magnetic flow path at least partially.
3. The magnetic convection heat pump according to claim 1 or 2 wherein said circulation path comprises

a length of conduit.

4. The magnetic convection heat pump according to claim 1 or 2 wherein said magnetic fluid contains a particulate ferromagnetic material having an average particle size less than 30nm, said ferromagnetic material being a ferrite comprised of a divalent transitional metal and iron oxide.
5. The magnetic convection heat pump according to claim 1 or 2 wherein said magnetic fluid is an ionic liquid exhibit magnetism
6. The magnetic convection heat pump according to claim 1 or 2 wherein said heat receiving section and said heat discharging section are detachably connected to each other.
7. The magnetic convection heat pump according to claim 2 wherein said magnetic flow path extends in said heat receiving section and said magnetic pump section to form a common magnetic flow path for both of them.
8. The magnetic convection heat pump according to claim 2 wherein said heat receiving section and said magnetic pump are constructed from different materials having mutually different heat conductivity values.
9. The magnetic convection heat pump according to claim 2, wherein said magnetic fluid contains a particulate ferromagnetic material having a coating of an ionic surfactant, and wherein said magnet member has on their surfaces with which said magnetic fluid contacts a coating of the same ionic surfactant as the coating of said particulate ferromagnetic material.
10. The magnetic convection heat pump according to claim 2 wherein said magnet member has on their surfaces with which said magnetic fluid contacts an oil-repellent coating.

Fig. 1

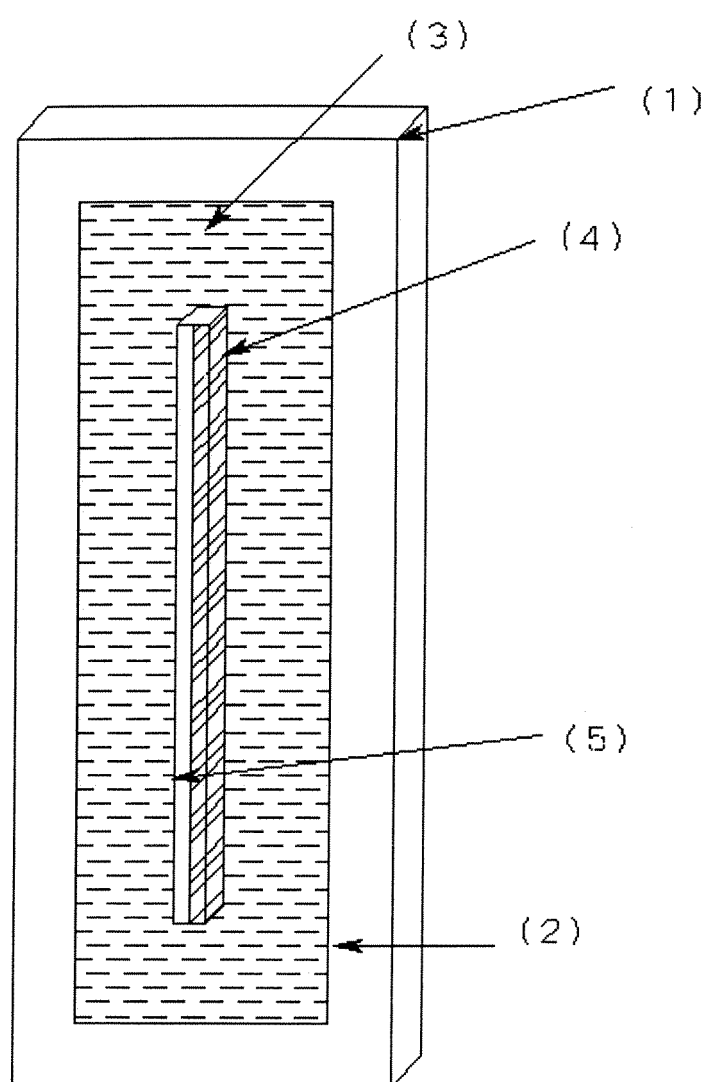


Fig. 2

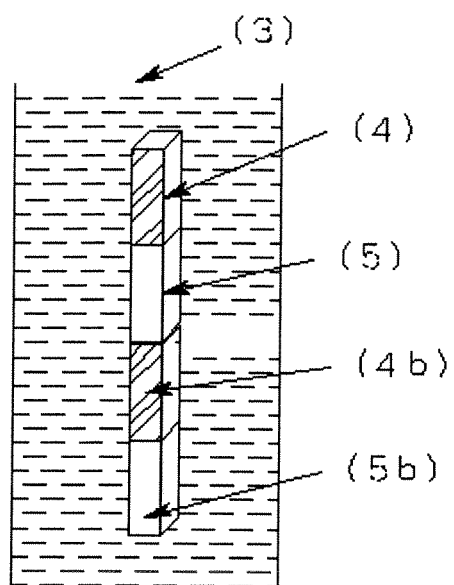


Fig. 3

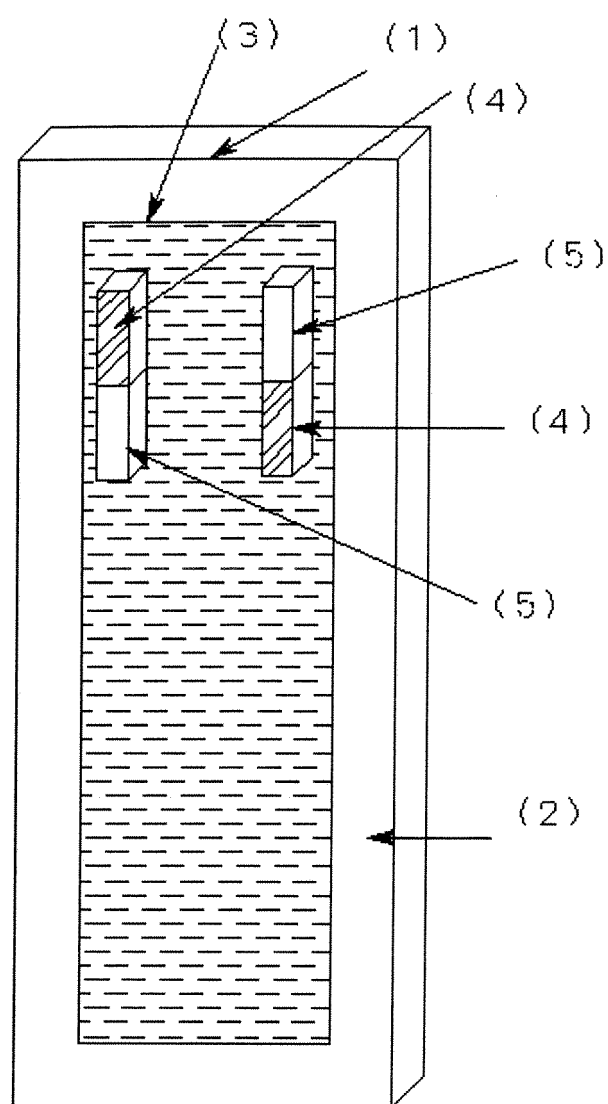


Fig. 4

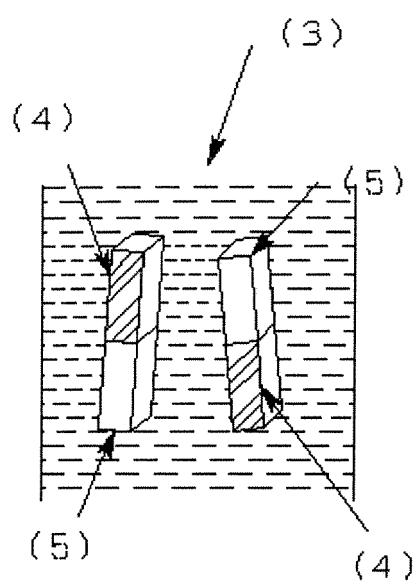


Fig. 5

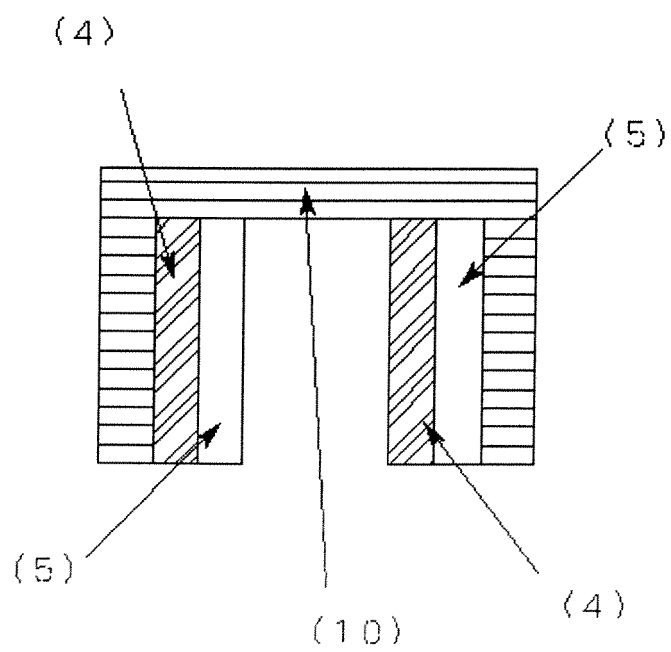


Fig. 6

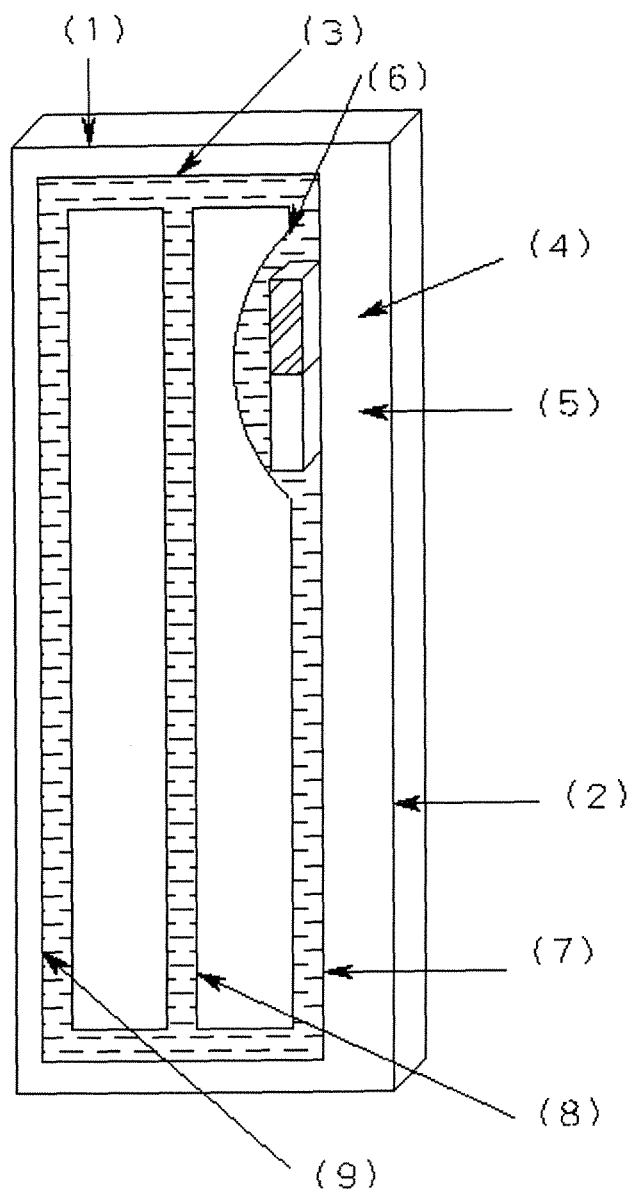


Fig. 7

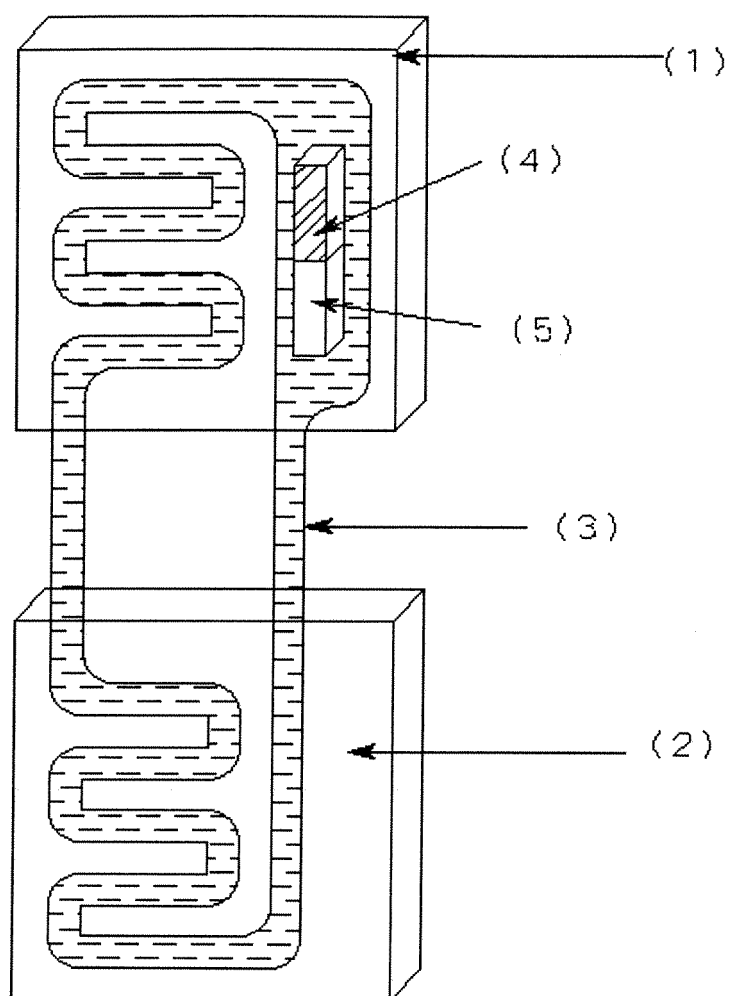


Fig. 8

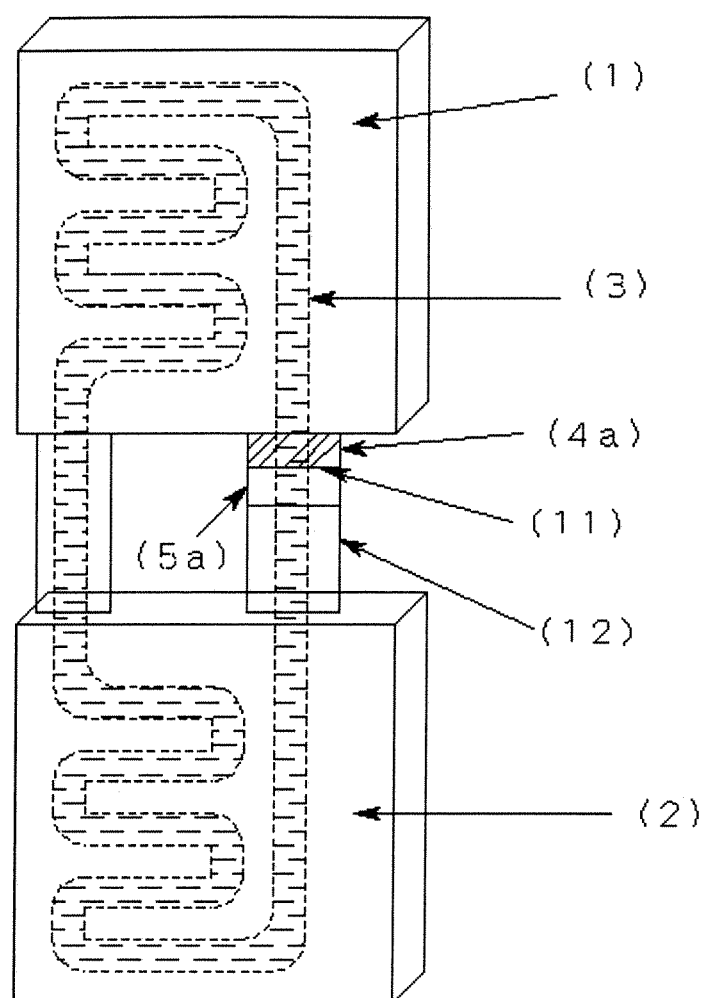


Fig. 9

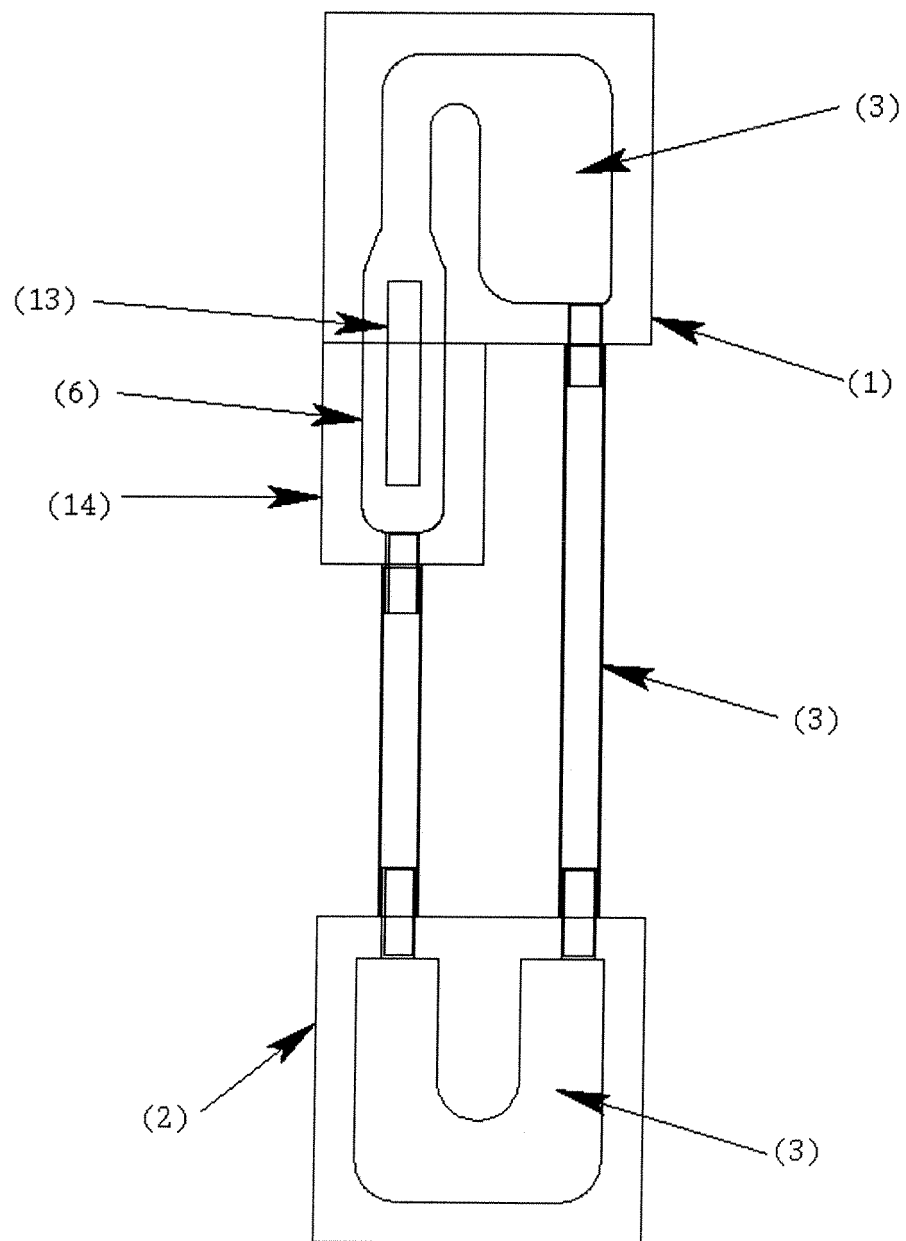


Fig. 10

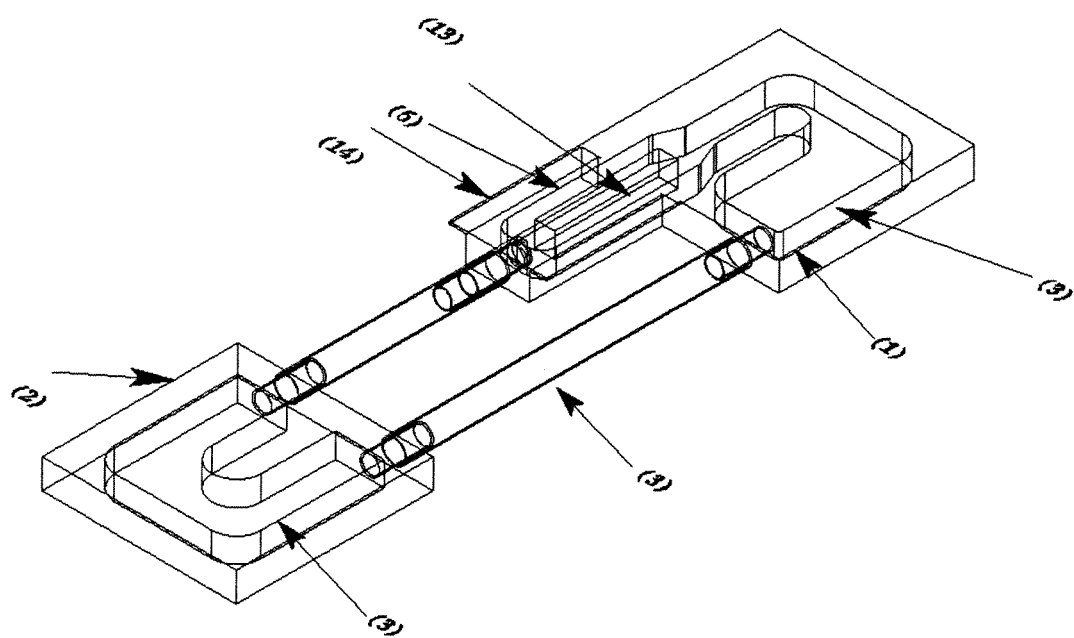
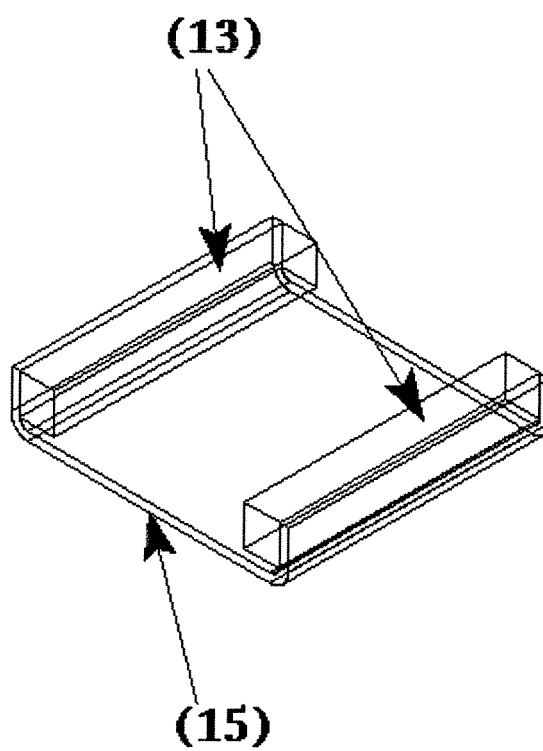


Fig. 11



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2005/021956

A. CLASSIFICATION OF SUBJECT MATTER

F28D15/02 (2006.01), **F25D9/00** (2006.01)

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)

F28D15/02 (2006.01), **F25D9/00** (2006.01)

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

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2006

Kokai Jitsuyo Shinan Koho 1971-2006 Toroku Jitsuyo Shinan Koho 1994-2006

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 11-183066 A (Toshiba Corp.), 06 July, 1999 (06.07.99), Par. Nos. [0019] to [0020]; Fig. 1 (Family: none)	1-3, 7-10 4-6
Y	JP 4-15489 A (Masato NAKATSUKA), 20 January, 1992 (20.01.92), Page 1, column 1, line 18 to page 2, column 4, line 15 (Family: none)	4, 5
Y	JP 3078605 U (Takayuki SUMITOMO), 10 July, 2001 (10.07.01), Claim 1; Fig. 1 (Family: none)	6

☐ 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
24 February, 2006 (24.02.06)Date of mailing of the international search report
07 March, 2006 (07.03.06)Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

Facsimile No.

Telephone No.

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 10231814 A [0003]
- JP 3102804 A [0003]