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(54) MAGNETIC REFRIGERATION SYSTEM

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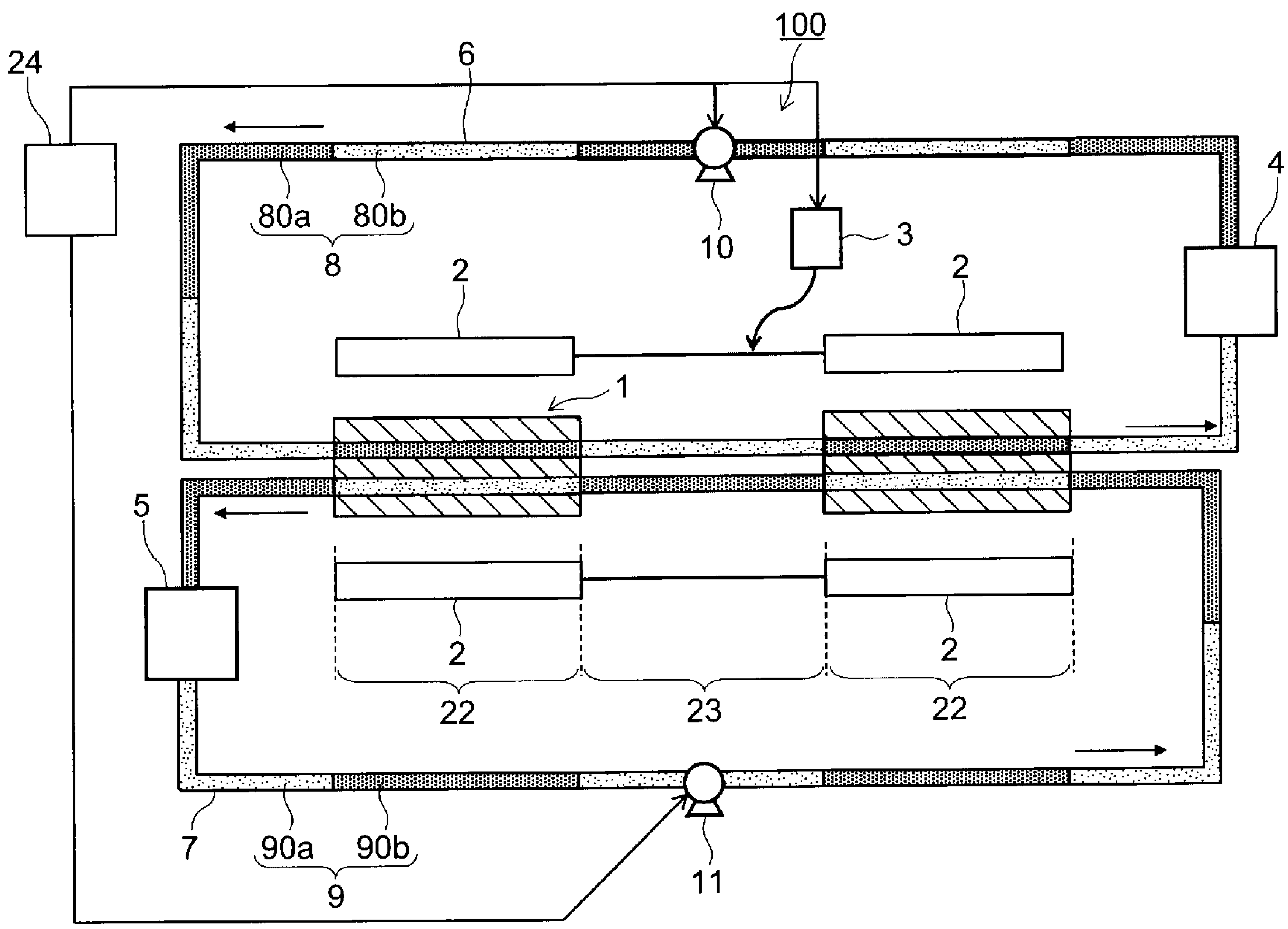
(57) **ABSTRACT**

According to one embodiment, a magnetic refrigeration system includes a first heat exchange section, a magnetic field changing section, a first heat transport medium, a second heat transport medium, and a transport section. The first heat exchange section includes a magnetocaloric effect material. The magnetic field changing section is configured to change magnetic field to the first heat exchange section. The second heat transport medium is separated from the first heat transport medium. The second heat transport medium is different from the first heat transport medium in specific heat per unit volume. The transport section is configured to sequentially feed the first heat exchange section with the first heat transport medium and the second heat transport medium.



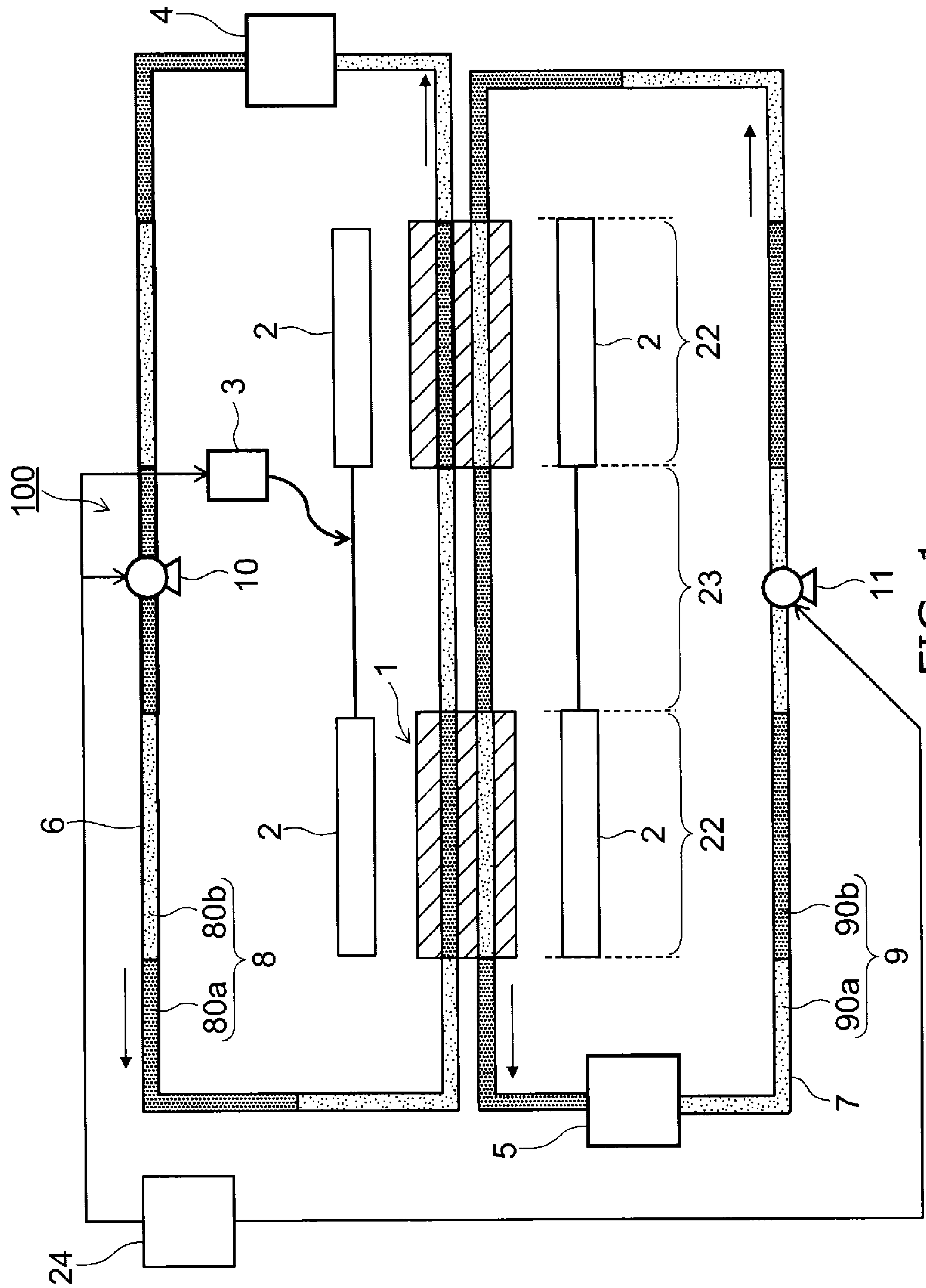


FIG. 1

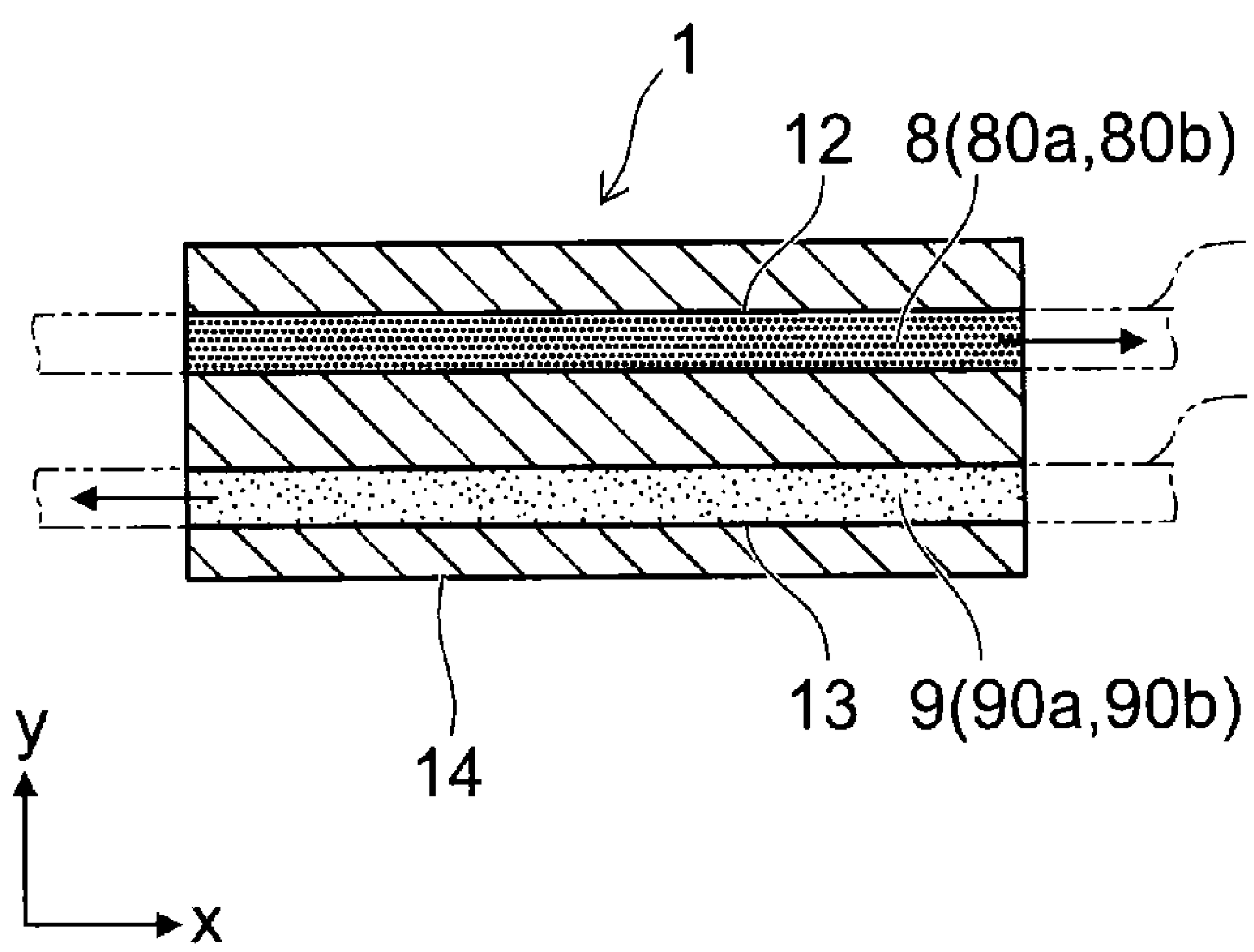

1
12
8(80a,80b)
6
7
13
9(90a,90b)
14
y
x

FIG. 2

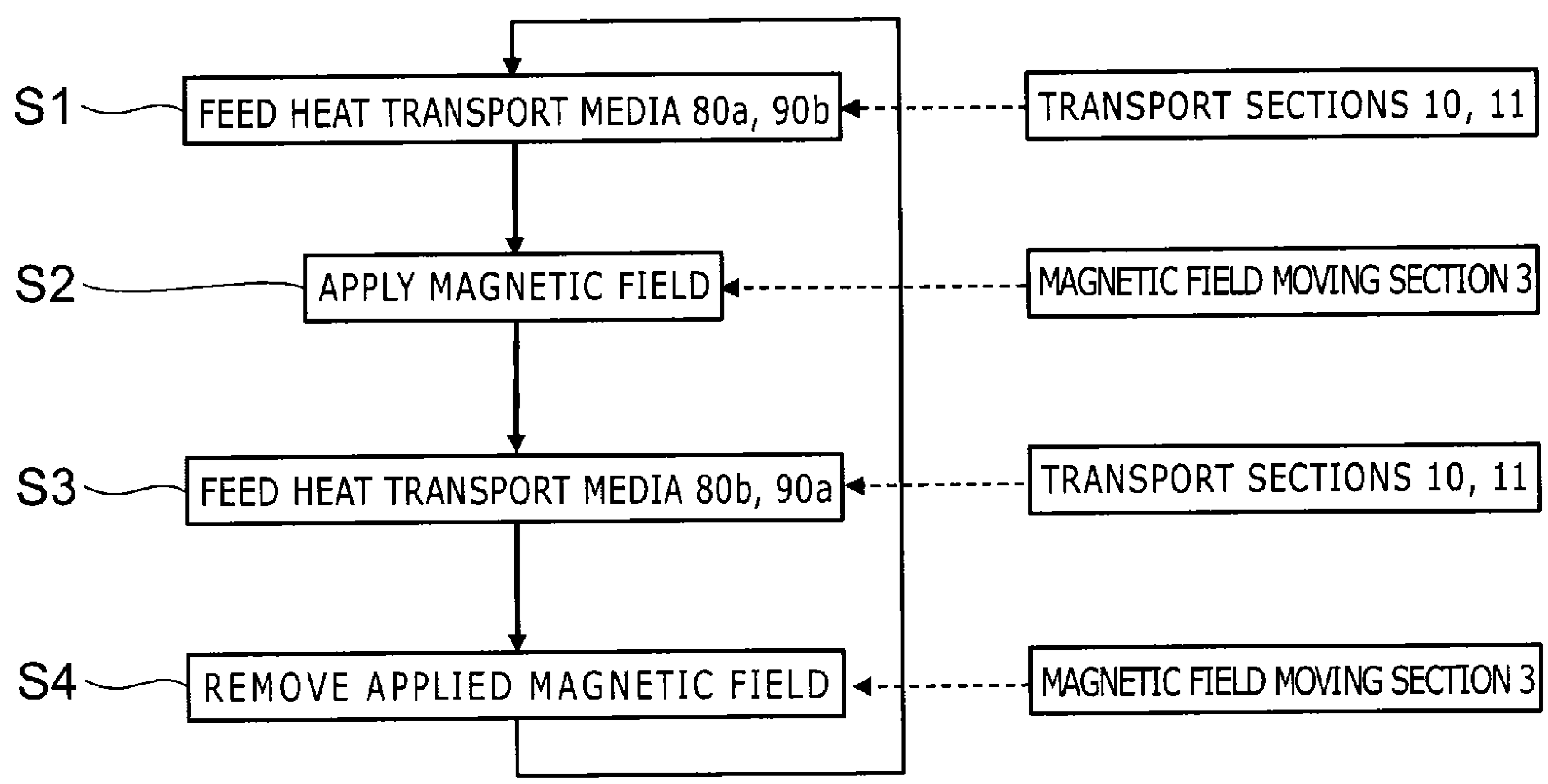

S1
FEED HEAT TRANSPORT MEDIA 80a, 90b
TRANSPORT SECTIONS 10, 11
S2
APPLY MAGNETIC FIELD
MAGNETIC FIELD MOVING SECTION 3
S3
FEED HEAT TRANSPORT MEDIA 80b, 90a
TRANSPORT SECTIONS 10, 11
S4
REMOVE APPLIED MAGNETIC FIELD
MAGNETIC FIELD MOVING SECTION 3

FIG. 3

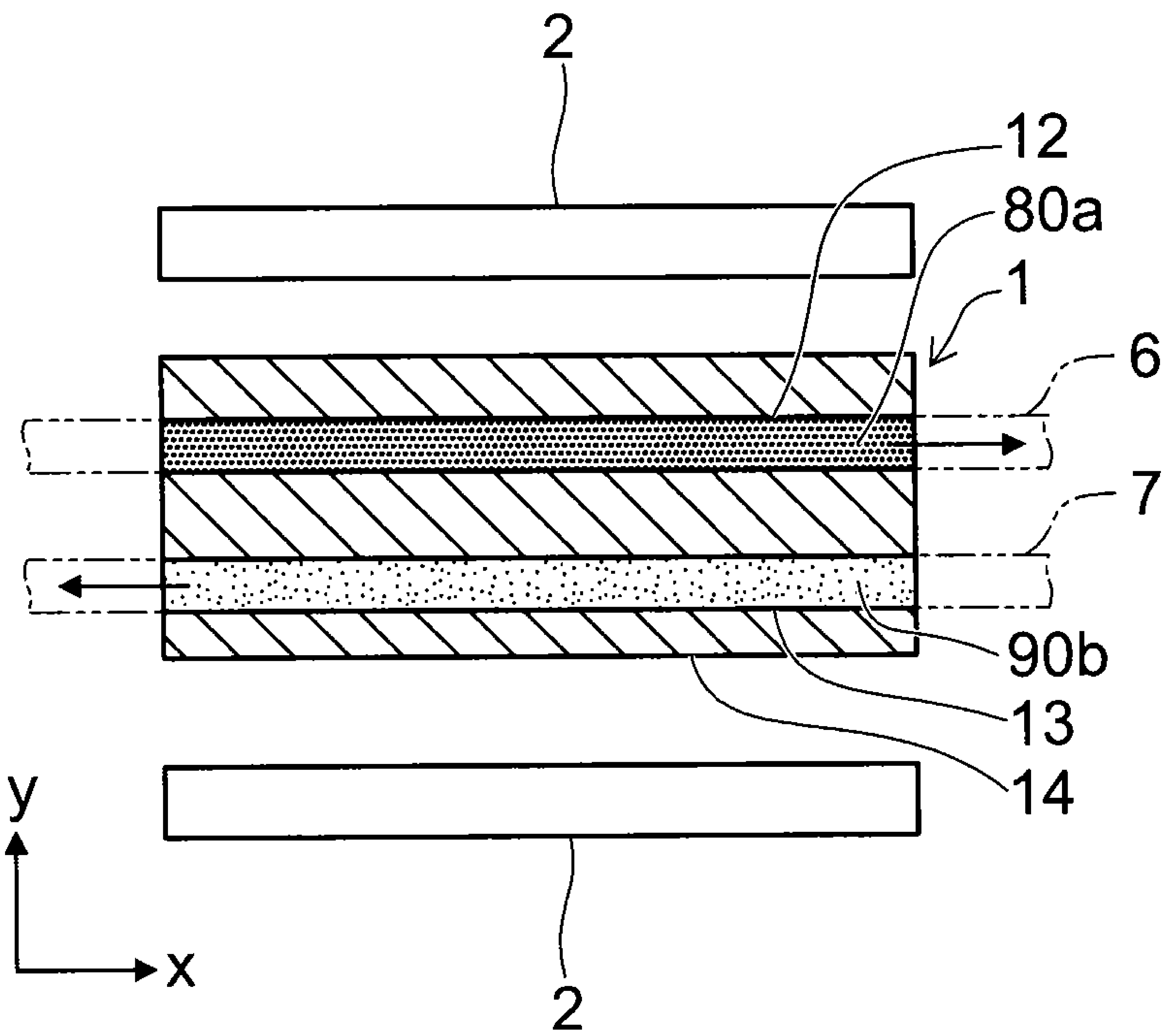


FIG. 4A

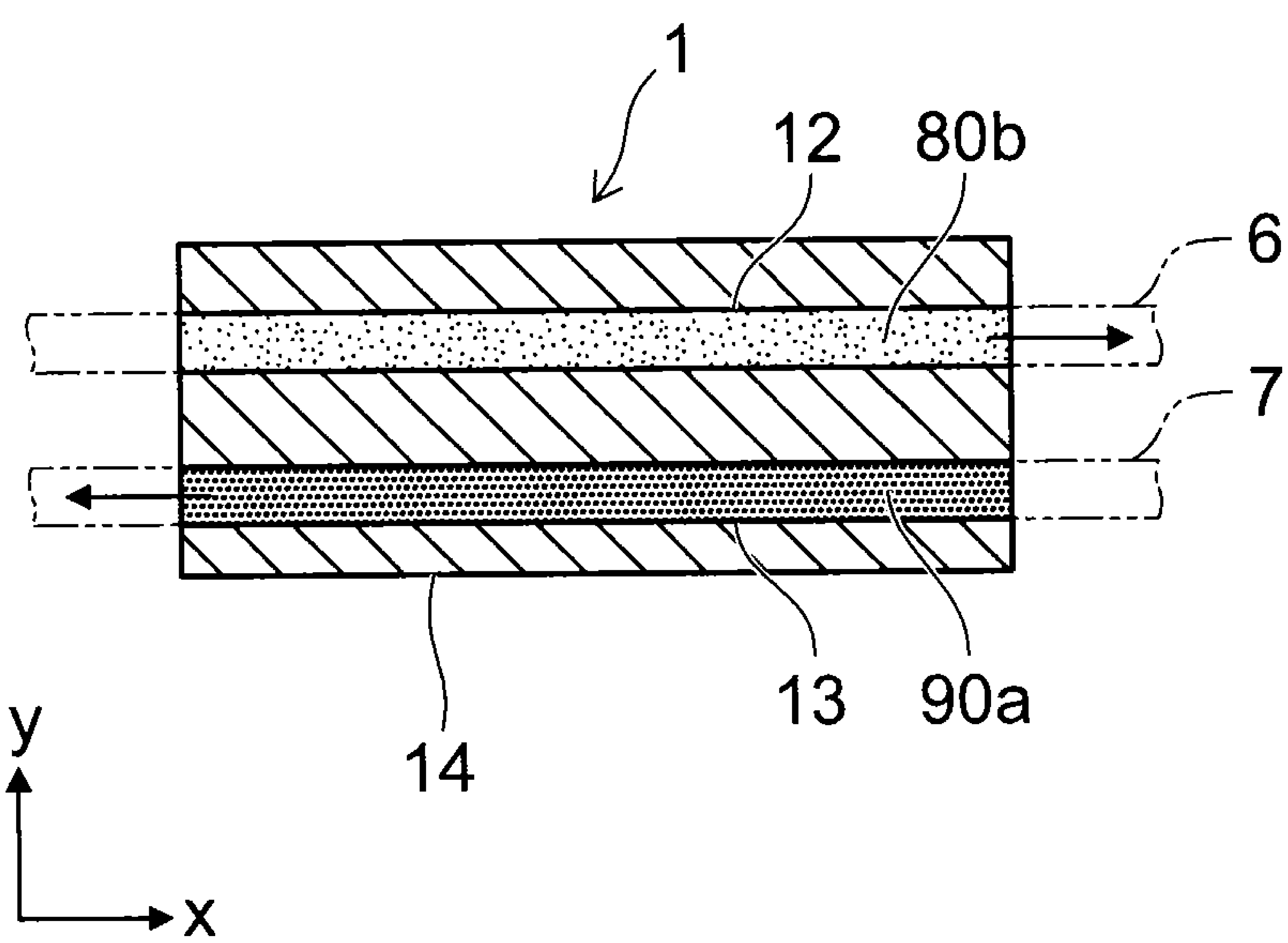


FIG. 4B

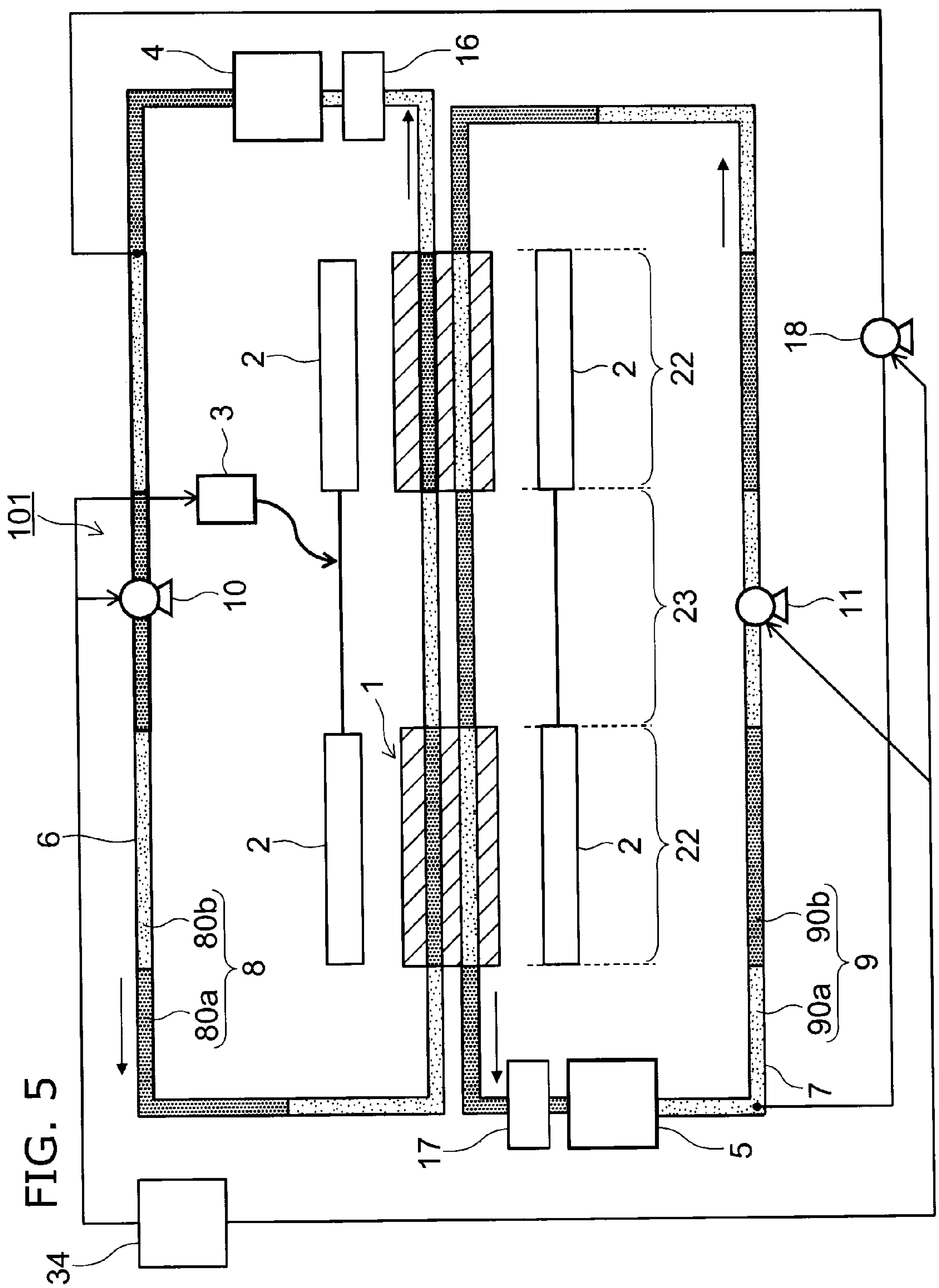


FIG. 5

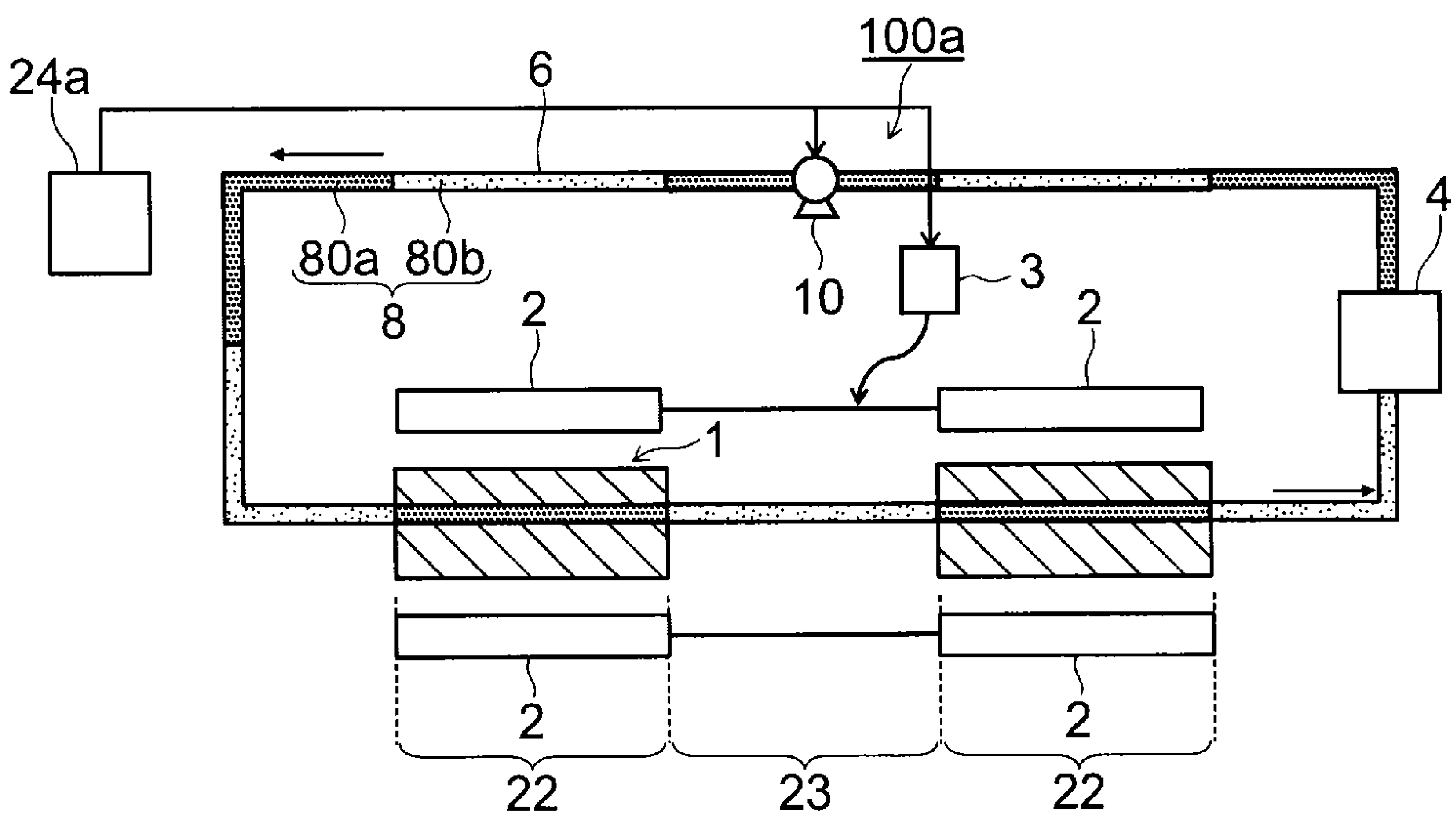

100a
24a
6
80a 80b
8
10
3
4
2
2
1
2
2
22
23
22

FIG. 6A

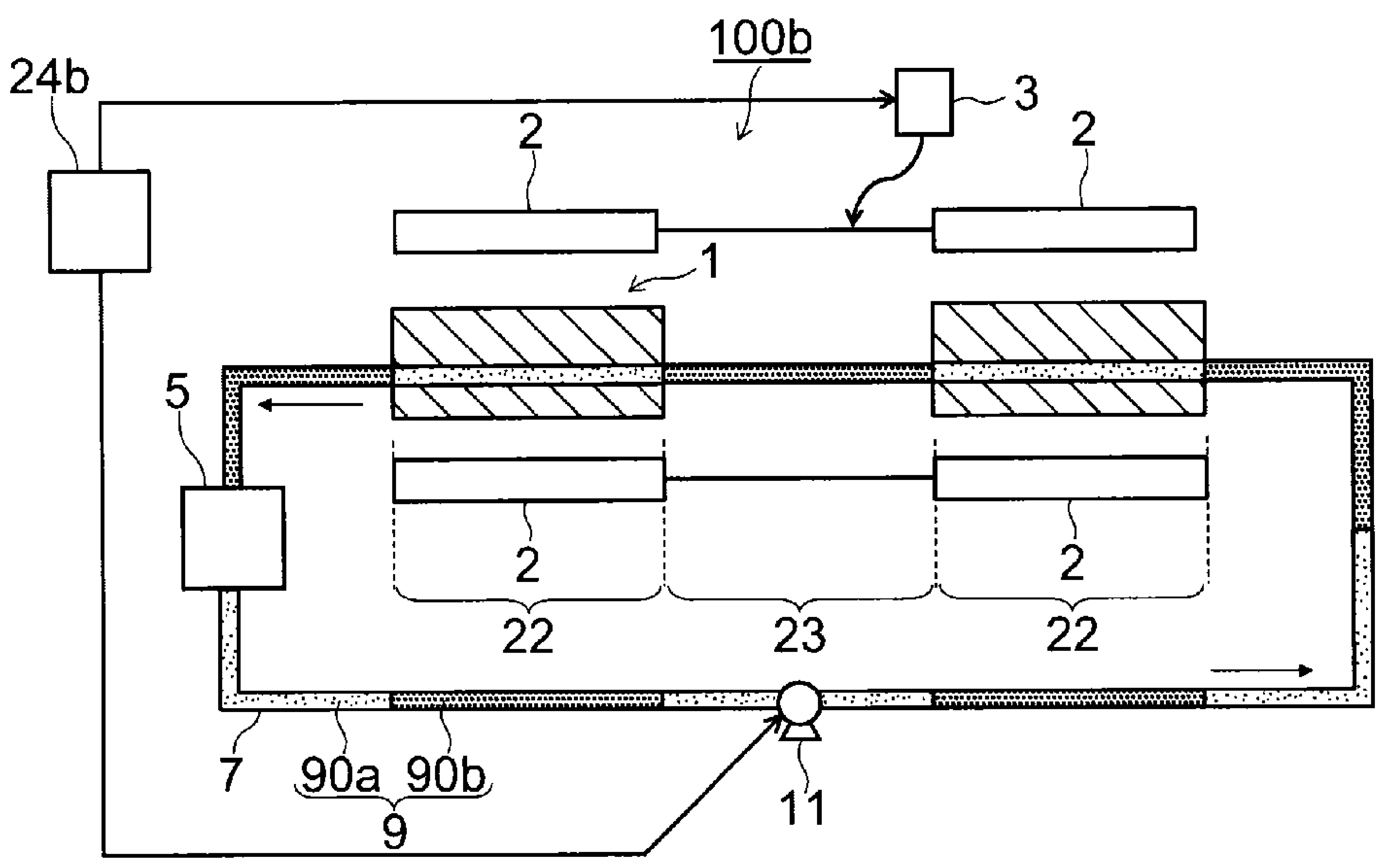
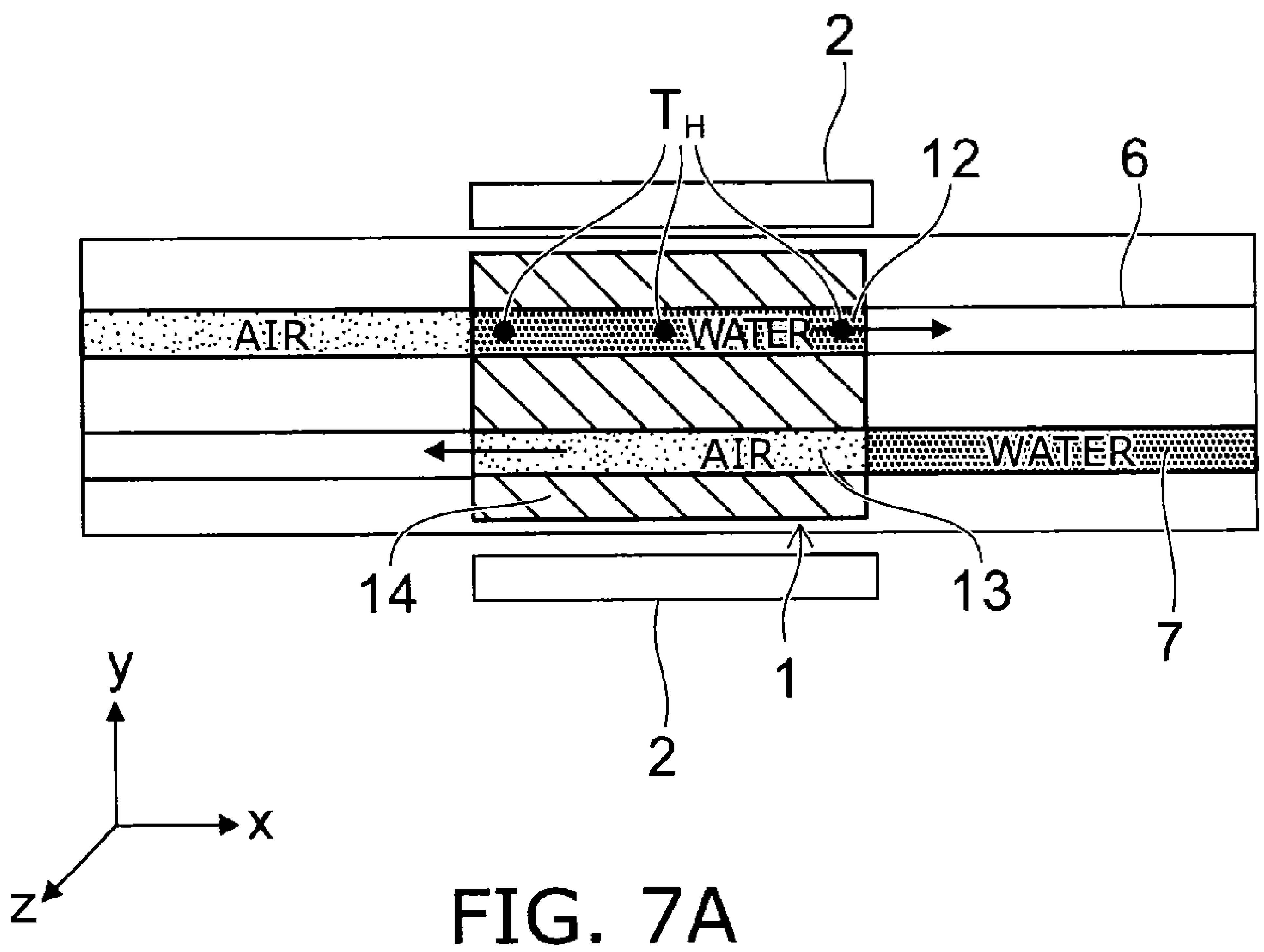
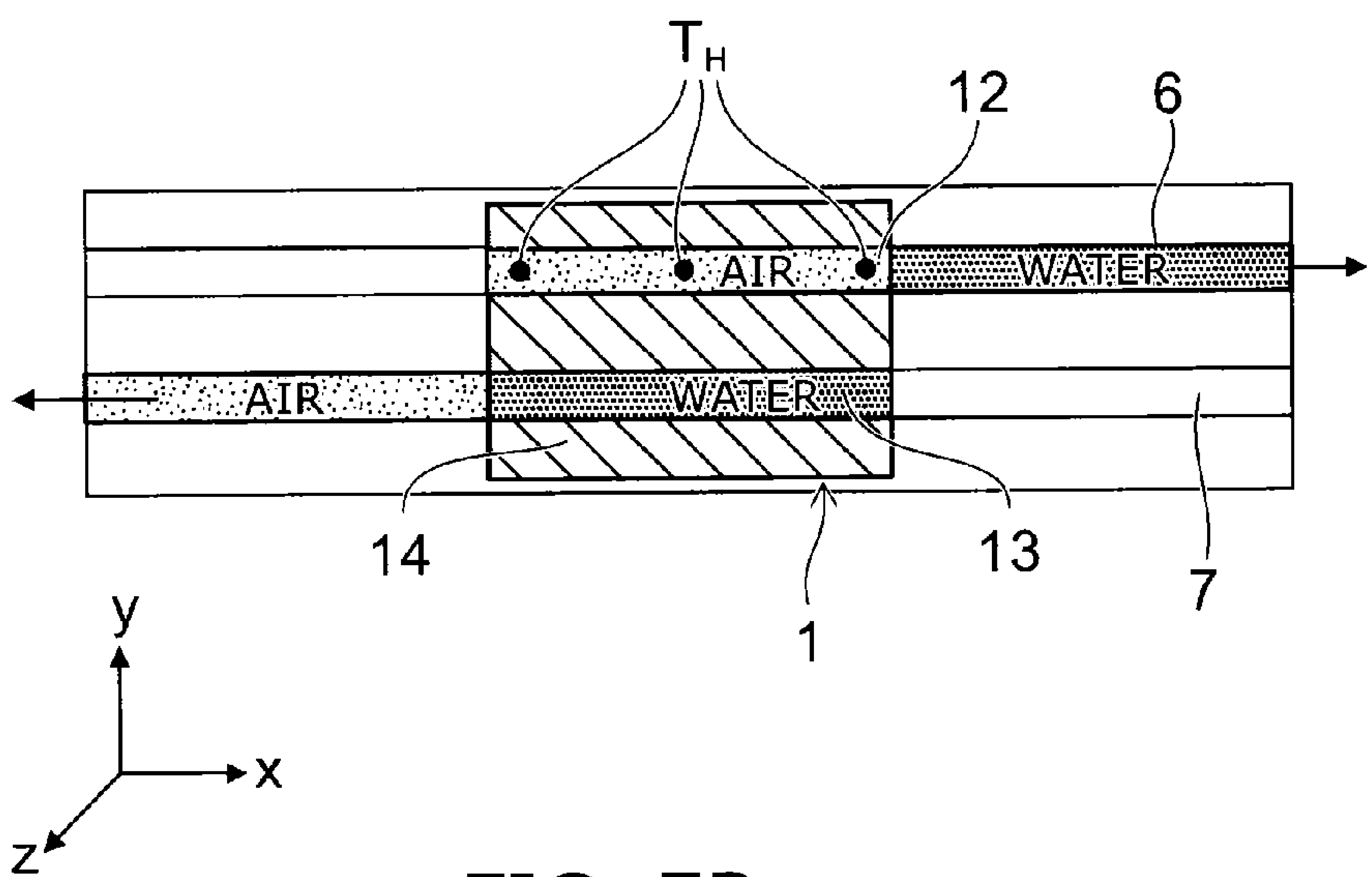

100b
24b
3
2
2
1
5
2
2
22
23
22
7
90a 90b
9
11

FIG. 6B



2
T_H
12
6
AIR
WATER
AIR
WATER
14
13
7
1
2
y
x
z

FIG. 7A



T_H
12
6
AIR
WATER
AIR
WATER
14
13
7
1
y
x
z

FIG. 7B

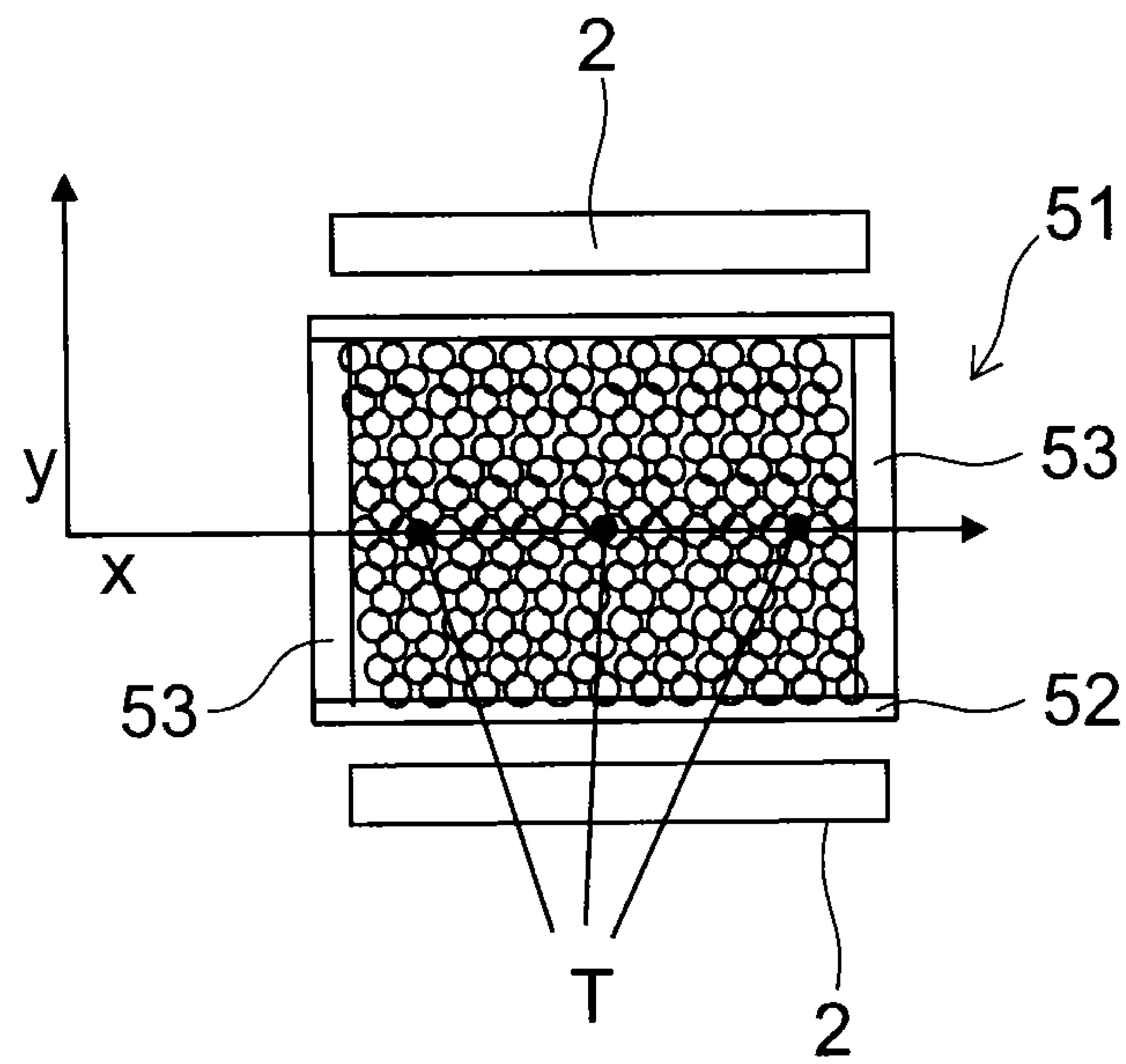

2
51
y
53
x
53
52
T
2

FIG. 8

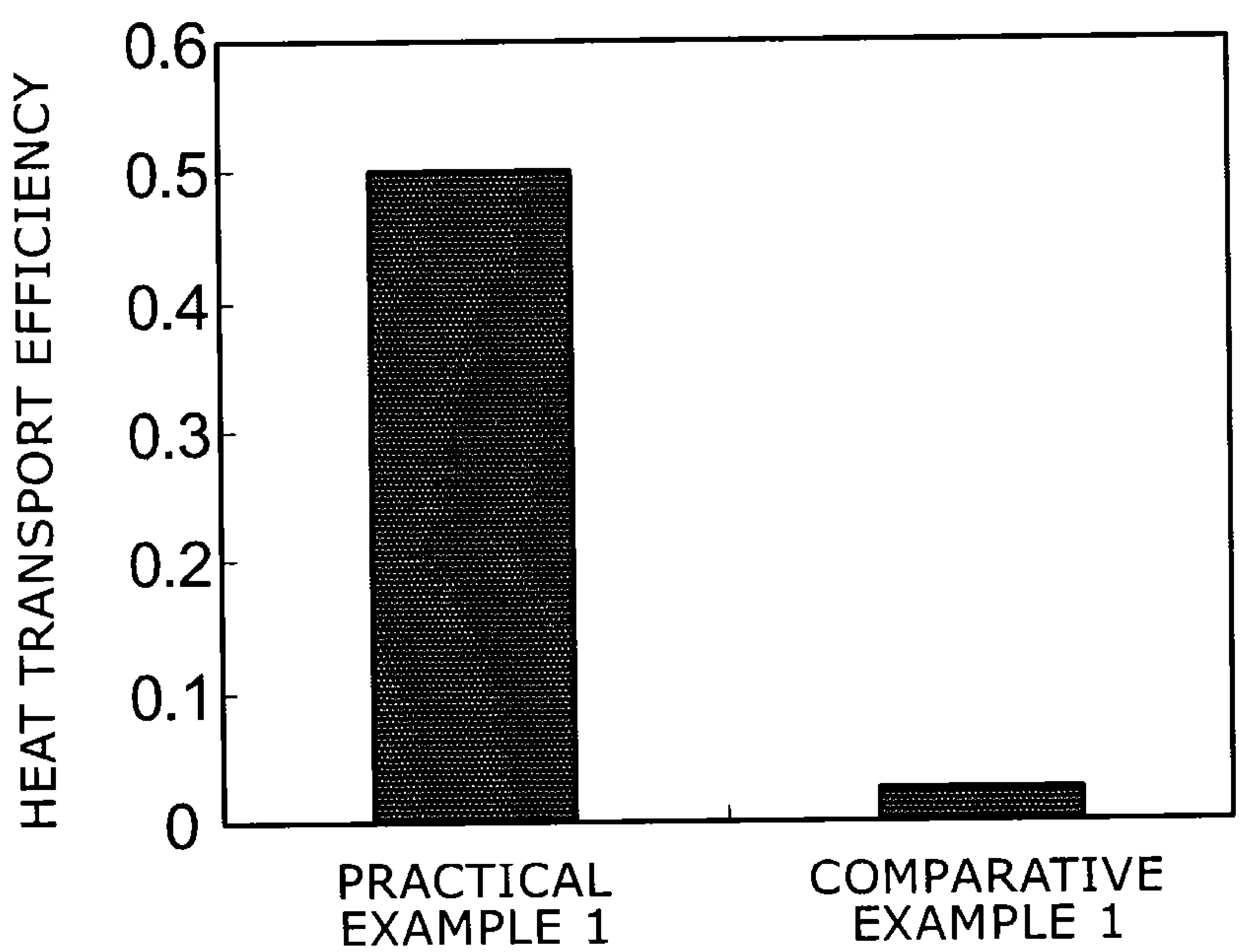

0.6
0.5
0.4
0.3
0.2
0.1
0
HEAT TRANSPORT EFFICIENCY
PRACTICAL EXAMPLE 1
COMPARATIVE EXAMPLE 1

FIG. 9

MAGNETIC REFRIGERATION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This is a continuation application of International Application PCT/JP2010/069297, filed on Oct. 29, 2010; the entire contents of which are incorporated herein by reference.

FIELD

[0002] Embodiments described herein relate generally to a magnetic refrigeration system.

BACKGROUND

[0003] Recently, as one of the environment-conscious and efficient refrigeration technologies, the magnetic refrigeration technology using the magnetocaloric effect has been raising expectations and activating research and development. In the magnetic refrigeration technology, a magnetic refrigeration cycle is configured using the magnetocaloric effect to produce a high temperature section and a low temperature section.

[0004] As one of such magnetic refrigeration technologies, the refrigeration technology called the AMR (active magnetic regenerative refrigeration) technique is proposed. Conventionally, the lattice entropy has been placed as an impediment to magnetic refrigeration in the cryogenic region. However, the AMR technique rather actively utilizes the lattice entropy. In the AMR technique, the magnetic refrigeration operation using the magnetocaloric effect is performed by a component including a magnetocaloric effect material. Simultaneously, the cold heat generated by this magnetic refrigeration operation is stored in that component.

[0005] The AMR technique can achieve a higher heat exchange efficiency than the gas refrigeration technology using the gas compression-expansion cycle.

[0006] However, from the viewpoint of energy saving and the like, further improvement in heat exchange efficiency is desired.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a schematic view for illustrating a magnetic refrigeration system according to a first embodiment;

[0008] FIG. **2** is a schematic sectional view for illustrating the heat exchange section;

[0009] FIG. **3** is a flow chart for illustrating the function of the heat exchange section according to the first embodiment;

[0010] FIGS. **4**A and **4**B are schematic sectional views for illustrating heat exchange in the heat exchange section according to the first embodiment;

[0011] FIG. **5** is a schematic view for illustrating a magnetic refrigeration system according to a second embodiment;

[0012] FIGS. **6**A and **6**B are schematic views for illustrating magnetic refrigeration systems according to a third embodiment;

[0013] FIGS. **7**A and **7**B are schematic sectional views for illustrating the heat exchange section **1** of the magnetic refrigeration system according to the embodiment;

[0014] FIG. **8** is a schematic sectional view for illustrating a heat exchange section **51** of the AMR magnetic refrigeration system according to the comparative example; and

[0015] FIG. **9** is a graph showing the comparison between the heat transport efficiency in Practical example 1 and the heat transport efficiency in Comparative example 1.

DETAILED DESCRIPTION

[0016] In general, according to one embodiment, a magnetic refrigeration system includes a first heat exchange section, a magnetic field changing section, a first heat transport medium, a second heat transport medium, and a transport section.

[0017] The first heat exchange section includes a magnetocaloric effect material.

[0018] The magnetic field changing section is configured to change magnetic field to the first heat exchange section.

[0019] The second heat transport medium is separated from the first heat transport medium.

The second heat transport medium is different from the first heat transport medium in specific heat per unit volume.

[0020] The transport section is configured to sequentially feed the first heat exchange section with the first heat transport medium and the second heat transport medium.

[0021] Embodiments will now be illustrated with reference to the drawings. In the drawings, similar components are labeled with like reference numerals, and the detailed description thereof is omitted appropriately.

First Embodiment

[0022] FIG. **1** is a schematic view for illustrating a magnetic refrigeration system according to a first embodiment.

[0023] As shown in FIG. **1**, the magnetic refrigeration system **100** includes a heat exchange section (ARM bed) **1** (first heat exchange section), a magnetic field generating section **2**, a moving section **3**, a high temperature side heat exchange section **4** (second heat exchange section), a low temperature side heat exchange section **5** (second heat exchange section), a piping **6**, a piping **7**, a heat transport medium **8**, a heat transport medium **9**, a transport section **10**, a transport section **11**, and a control section **24**.

[0024] FIG. **2** is a schematic sectional view for illustrating the heat exchange section.

[0025] In FIG. **2**, the moving direction of the heat transport medium **8**, **9** is taken as x direction, and a direction perpendicular thereto is taken as y direction.

[0026] The heat exchange section **1** including a magnetocaloric effect material includes a region **14**, a region **12** (first region) connected to the piping **6**, and a region **13** (second region) connected to the piping **7**.

[0027] The region **14** is configured to include a magnetocaloric effect material. The region **14** can be configured to include a magnetocaloric effect material such as Gd (gadolinium).

[0028] The region **12** is provided so as to penetrate through the region **14**. Thus, the outer peripheral surface of the region **12** is in contact with the region **14**. The region **12** can be e.g. a channel penetrating through the region **14**.

[0029] The heat transport medium **8** fed through the piping **6** is enabled to flow through the region **12**.

[0030] The region **13** is provided so as to penetrate through the region **14**. Thus, the outer peripheral surface of the region **13** is in contact with the region **14**. The region **13** can be e.g. a channel penetrating through the region **14**.

[0031] The heat transport medium **9** fed through the piping **7** is enabled to flow through the region **13**.

[0032] Here, the heat transport medium **8** flowing through the region **12** and the heat transport medium **9** flowing through the region **13** are separated from each other by the region **14**. This prevents the heat transport medium **8** and the heat transport medium **9** from mixing with each other.

[0033] As described later, heat generation and heat absorption occur in the region **14**. Heat exchange occurs between the region **14** and the heat transport medium **8** located in the region **12**. Furthermore, heat exchange occurs between the region **14** and the heat transport medium **9** located in the region **13**.

[0034] Here, for instance, in the case where the region **12** is fed with a heat transport medium **80***a*, the region **13** is fed with a heat transport medium **90***b*. In the case where the region **12** is fed with a heat transport medium **80***b*, the region **13** is fed with a heat transport medium **90***a*.

[0035] The aforementioned region **14** preferably has a configuration (e.g., a plate-like body free from voids and the like) for passing the heat transport medium **8**, **9** and preventing the heat transport media from mixing with each other. However, the embodiment is not limited thereto.

[0036] For instance, a partition, not shown, for preventing passage of the heat transport medium can be provided between the region **14** and the region **12** and between the region **14** and the region **13**. For instance, a tubular body can be provided as the partition, not shown, so that the inside of the tubular body constitutes the region **12**, **13** and the outside of the tubular body constitutes the region **14**. Then, the region **14** can be formed from a sintered body including voids, or formed by packing granular bodies.

[0037] The magnetocaloric effect material is not limited to Gd (gadolinium) described above, but only need to be a material developing the magnetocaloric effect. The magnetocaloric effect material can be any of e.g. Gd compounds of Gd (gadolinium) mixed with various elements, intermetallic compounds made of various rare earth elements and transition metal elements, Ni_2MnGa alloys, GdGeSi compounds, $LaFe_{13}$-based compounds, and various magnetic materials such as $LaFe_{13}H$.

[0038] The magnetic field generating section **2** is placed outside the heat exchange section **1** and applies a magnetic field to the heat exchange section **1**.

[0039] The magnetic field generating section **2** can be e.g. a permanent magnet. The permanent magnet can be e.g. a NdFeB (neodymium-iron-boron) magnet, SmCo (samarium-cobalt) magnet, or ferrite magnet.

[0040] The moving section **3** is connected to the magnetic field generating section **2** and changes the relative position of the heat exchange section **1** and the magnetic field generating section **2**.

[0041] Here, changing the relative position means changing the relative position of the heat exchange section **1** and the magnetic field generating section **2** to enable switching between the position **22** (ON position) where the magnetic field generating section **2** applies the magnetic field to the heat exchange section **1** and the position **23** (OFF position) where the magnetic field generating section **2** does not apply the magnetic field to the heat exchange section **1**.

[0042] Thus, by causing the moving section **3** to change the relative position of the heat exchange section **1** and the magnetic field generating section **2**, the magnetic field can be applied to the heat exchange section **1**, and the magnetic field applied to the heat exchange section **1** can be removed. In the heat exchange section **1**, heat generation and heat absorption occur by application of the magnetic field and removal of the magnetic field. The details on the function of the heat exchange section **1** will be described later.

[0043] The moving section **3** can be e.g. a section for applying mechanical variation to the magnetic field generating section **2** to change the relative position of the heat exchange section **1** and the magnetic field generating section **2**.

[0044] In the case illustrated in FIG. **1**, the magnetic field generating section **2** and the moving section **3** constitute a magnetic field changing section for changing the magnetic field to the heat exchange section **1**.

[0045] In the case illustrated in FIG. **1**, the moving section **3** is connected to the magnetic field generating section **2** to apply mechanical variation to the magnetic field generating section **2**. However, alternatively, the moving section **3** may be connected to the heat exchange section **1** to apply mechanical variation to the heat exchange section **1**.

[0046] The moving section **3** can include e.g. driving means such as a motor.

[0047] In the foregoing, as the magnetic field generating section **2**, a permanent magnet is illustrated. However, for instance, an electromagnet can also be used as the magnetic field generating section **2**. In the case of using an electromagnet as the magnetic field generating section **2**, the moving section **3** can be configured to apply mechanical variation to the magnetic field generating section **2**. However, alternatively, the moving section **3** can also be configured as e.g. a switch for switching between energization and deenergization of the electromagnet.

[0048] The high temperature side heat exchange section **4** performs heat exchange between the heat transport medium **8** heated in the heat exchange section **1** and a heat exchange target, not shown. The high temperature side heat exchange section **4** can be e.g. a section for heating air by performing heat exchange between the heat transport medium **8** at high temperature and air.

[0049] The low temperature side heat exchange section **5** performs heat exchange between the heat transport medium **9** subjected to heat absorption in the heat exchange section **1** and a heat exchange target, not shown. The low temperature side heat exchange section **5** can be e.g. a section for cooling air by performing heat exchange between the heat transport medium **9** at low temperature and air.

[0050] The piping **6** connects the heat exchange section **1**, the high temperature side heat exchange section **4**, and the transport section **10** in a closed loop. Thus, the heat transport medium **8** can be circulated in the closed loop channel formed from the heat exchange section **1**, the high temperature side heat exchange section **4**, the transport section **10**, and the piping **6**.

[0051] The piping **7** connects the heat exchange section **1**, the low temperature side heat exchange section **5**, and the transport section **11** in a closed loop. Thus, the heat transport medium **9** can be circulated in the closed loop channel formed from the heat exchange section **1**, the low temperature side heat exchange section **5**, the transport section **11**, and the piping **7**.

[0052] The heat transport medium **8** can be composed of two or more heat transport media different in specific heat per unit volume. The heat transport medium **8** is composed of e.g. a heat transport medium **80***a* (first heat transport medium) and a heat transport medium **80***b* (second heat transport medium) having a lower specific heat per unit volume than the heat transport medium **80***a*.

[0053] The heat transport medium **9** can be composed of two or more heat transport media different in specific heat per unit volume. The heat transport medium **9** is composed of e.g.

a heat transport medium **90***a* (first heat transport medium) and a heat transport medium **90***b* (second heat transport medium) having a lower specific heat per unit volume than the heat transport medium **90***a*.

[0054] The heat transport medium **80***a* and the heat transport medium **80***b* are separated from each other. The heat transport medium **90***a* and the heat transport medium **90***b* are separated from each other.

[0055] Here, being separated means that heat transport media different in specific heat per unit volume form respective phases with respect to the moving direction of the heat transport media.

[0056] In forming phases, it is preferable that each heat transport medium be not mixed with a different heat transport medium. However, the case where a particular heat transport medium is mixed with a different heat transport medium in a volume ratio of 30% or less may also be regarded as forming respective phases.

[0057] For instance, the heat transport media can be water and air, which has a lower specific heat per unit volume than water. In this case, air may partially dissolve in water. However, the solubility of air in water is 0 vol % or more and 30 vol % or less. Thus, air and water can form respective phases. That is, it can be regarded that the water phase and the air phase are separated.

[0058] The heat transport medium may be any of gas, liquid, and solid. Heat transport media different in specific heat per unit volume can be appropriately selected for use.

[0059] In this case, it is preferable to use a combination with a large difference in specific heat per unit volume. For instance, combinations such as gas-liquid, solid-liquid, and solid-gas can be used.

[0060] A heat transport medium of gas can be e.g. air or nitrogen gas. A heat transport medium of gas can reduce pressure loss during transportation. A heat transport medium of liquid can be e.g. water, an oil-based medium such as mineral oil and silicone, or a solvent-based medium such as alcohols (e.g., ethylene glycol).

[0061] In this case, water has the highest specific heat and is inexpensive. However, water may freeze in the temperature region of 0° C. or less. Thus, it is preferable to use e.g. an oil-based medium, a solvent-based medium, a mixed liquid of water and an oil-based medium, or a mixed liquid of water and a solvent-based medium. Depending on the operating temperature region of the magnetic refrigeration system **100**, the liquid can be appropriately changed in kind and mixing ratio.

[0062] A heat transport medium of solid can be e.g. resin, metal, or inorganic material such as ceramic.

[0063] In this case, for instance, the heat transport medium of solid can be integrally configured, or a granular solid aggregate can be used as the heat transport medium. However, the integrally configured heat transport medium of solid can suppress mixing with a different heat transport medium.

[0064] The heat transport medium **8** and the heat transport medium **9** can have either the same configuration or different configurations.

[0065] The transport section **10** circulates the heat transport medium **8** in the closed loop channel formed from the heat exchange section **1**, the high temperature side heat exchange section **4**, the transport section **10**, and the piping **6**. More specifically, the heat transport medium **80***a* and the heat transport medium **80***b* are sequentially fed into the heat exchange section **1**. The heat transport medium **80***a* and the heat transport medium **80***b* heated in the heat exchange section **1** are sent to the high temperature side heat exchange section **4**. The heat transport medium **80***a* and the heat transport medium **80***b* heat-exchanged with the heat exchange target, not shown, in the high temperature side heat exchange section **4** are sent again to the heat exchange section **1**.

[0066] The transport section **11** circulates the heat transport medium **9** in the closed loop channel formed from the heat exchange section **1**, the low temperature side heat exchange section **5**, the transport section **11**, and the piping **7**. More specifically, the heat transport medium **90***a* and the heat transport medium **90***b* are sequentially fed into the heat exchange section **1**. The heat transport medium **90***a* and the heat transport medium **90***b* subjected to heat absorption in the heat exchange section **1** are sent to the low temperature side heat exchange section **5**. The heat transport medium **90***a* and the heat transport medium **90***b* heat-exchanged with the heat exchange target, not shown, in the low temperature side heat exchange section **5** are sent again to the heat exchange section **1**.

[0067] The transport section **10**, **11** can be e.g. any of various pumps.

[0068] The control section **24** controls the operation of the moving section **3**, the transport section **10**, and the transport section **11**.

[0069] More specifically, when the heat exchange section **1** is fed with the heat transport medium **80***a* and the heat transport medium **90***b*, the control section **24** controls the operation of the moving section **3**, the transport section **10**, and the transport section **11** so as to apply a magnetic field to the heat exchange section **1**. When the heat exchange section **1** is fed with the heat transport medium **80***b* and the heat transport medium **90***a*, the control section **24** controls the operation of the moving section **3**, the transport section **10**, and the transport section **11** so as to remove the magnetic field applied to the heat exchange section **1**.

[0070] For instance, in performing heat generation, the transport section **10** is controlled to feed the heat exchange section **1** with the heat transport medium **80***a* having a higher specific heat per unit volume than the heat transport medium **80***b*. Furthermore, the moving section **3** constituting the magnetic field changing section is controlled to apply a magnetic field to the heat exchange section **1**.

[0071] For instance, in performing heat absorption, the transport section **11** is controlled to feed the heat exchange section **1** with the heat transport medium **90***a* having a higher specific heat per unit volume than the heat transport medium **90***b*. Furthermore, the moving section **3** constituting the magnetic field changing section is controlled to remove the magnetic field from the heat exchange section **1**.

[0072] The relationship between application of the magnetic field and removal of the magnetic field in the heat exchange section **1** and the heat transport media different in specific heat per unit volume will be described later.

[0073] Next, the function of the magnetic refrigeration system **100** is illustrated.

[0074] FIG. **3** is a flow chart for illustrating the function of the heat exchange section according to the first embodiment.

[0075] FIGS. **4**A and **4**B are schematic sectional views for illustrating heat exchange in the heat exchange section according to the first embodiment. More specifically, FIG. **4**A shows the case of applying a magnetic field to the heat exchange section **1**. FIG. **4**B shows the case of removing the magnetic field applied to the heat exchange section.

[0076] First, as shown in FIG. **3**, the heat exchange section **1** is fed with the heat transport medium **80***a* and the heat transport medium **90***b* (step S**1**).

[0077] More specifically, the control section **24** controls the transport section **10** to feed the heat transport medium **80***a* into the region **12** of the heat exchange section **1**. Furthermore, the control section **24** controls the transport section **11** to feed the heat transport medium **90***b* into the region **13** of the heat exchange section **1**.

[0078] Next, the control section **24** controls the moving section **3** to move the magnetic field generating section **2** to the position **22** (ON position) for applying a magnetic field to the heat exchange section **1** (step S**2**).

[0079] The state at this time is as illustrated in FIG. **4**A.

[0080] When the magnetic field is applied to the heat exchange section **1**, the magnetocaloric effect material forming the region **14** generates heat. Thus, the generated heat is absorbed by the transport medium **80***a* fed into the region **12** and the transport medium **90***b* fed into the region **13**.

[0081] Next, the control section **24** controls the transport section **10** to feed the heat transport medium **80***b* into the region **12** of the heat exchange section **1**. Furthermore, the control section **24** controls the transport section **11** to feed the heat transport medium **90***a* into the region **13** of the heat exchange section **1** (step S**3**).

[0082] Thus, the transport medium **80***a* is ejected from the region **12** toward the high temperature side heat exchange section **4**. The transport medium **90***b* is ejected from the region **13** toward the low temperature side heat exchange section **5**.

[0083] Next, the control section **24** controls the moving section **3** to move the magnetic field generating section **2** to the position **23** (OFF position) for not applying a magnetic field to the heat exchange section **1** (step S**4**).

[0084] The state at this time is as illustrated in FIG. **4**B.

[0085] When the magnetic field applied to the heat exchange section **1** is removed, the magnetocaloric effect material forming the region **14** absorbs heat. Thus, heat is drawn from the heat transport medium **80***b* fed into the region **12** and the heat transport medium **90***a* fed into the region **13**.

[0086] After step S4, control returns to step S1.

[0087] More specifically, the control section **24** controls the transport section **10** to feed the heat transport medium **80***a* into the region **12** of the heat exchange section **1**. Furthermore, the control section **24** controls the transport section **11** to feed the heat transport medium **90***b* into the region **13** of the heat exchange section **1**.

[0088] Thus, the transport medium **80***b* is ejected from the region **12** toward the high temperature side heat exchange section **4**. The transport medium **90***a* is ejected from the region **13** toward the low temperature side heat exchange section **5**.

[0089] By repeating the foregoing procedure, the heat transport medium **8** (heat transport media **80***a*, **80***b*) is sent to the high temperature side heat exchange section **4**. The heat transport medium **9** (heat transport media **90***a*, **90***b*) is sent to the low temperature side heat exchange section **5**.

[0090] Then, for instance, heat taken out of the heat transport medium **8** in the high temperature side heat exchange section **4** can be used for air heating. Furthermore, for instance, heat can be absorbed by the heat transport medium **9** in the low temperature side heat exchange section **5** for air cooling.

[0091] Here, heat generation of the magnetocaloric effect material by application of a magnetic field and heat absorption of the magnetocaloric effect material by removal of the applied magnetic field are known phenomena, and thus the description thereof is omitted.

[0092] Next, feeding the regions **12**, **13** of the heat exchange section **1** with heat transport media different in specific heat per unit volume is further described.

[0093] By application of a magnetic field, heat is generated by the magnetocaloric effect material and absorbed by heat transport media different in specific heat per unit volume. In this case, even under the same temperature environment, more heat is absorbed by the heat transport medium having a higher specific heat per unit volume.

[0094] By removal of the applied magnetic field, heat is absorbed by the magnetocaloric effect material to draw heat from heat transport media different in specific heat per unit volume. In this case, even under the same temperature environment, more heat is drawn from the heat transport medium having a higher specific heat per unit volume.

[0095] Here, in step S**2**, the magnetocaloric effect material generates heat. In this step, the heat transport medium **80***a* having a high specific heat per unit volume is fed into the region **12** of the heat exchange section **1**, and the heat transport medium **90***b* having a low specific heat per unit volume is fed into the region **13** of the heat exchange section **1**.

[0096] Thus, more heat from the magnetocaloric effect material is absorbed by the heat transport medium **80***a* having a higher specific heat per unit volume. That is, heat is selectively provided to the heat transport medium **80***a*.

[0097] On the other hand, in step S4, the magnetocaloric effect material absorbs heat. In this step, the heat transport medium **80***b* having a low specific heat per unit volume is fed into the region **12** of the heat exchange section **1**, and the heat transport medium **90***a* having a high specific heat per unit volume is fed into the region **13** of the heat exchange section **1**.

[0098] Thus, a larger amount of heat is drawn from the heat transport medium **90***b* having a higher specific heat per unit volume. That is, heat is selectively drawn from the heat transport medium **90***b*.

[0099] Here, in the heat transport medium **8**, in step S2 in which the magnetocaloric effect material generates heat, the heat transport medium **80***a* having a high specific heat per unit volume is fed into the region **12** of the heat exchange section **1**. In step S4 in which the magnetocaloric effect material absorbs heat, the heat transport medium **80***b* having a low specific heat per unit volume is fed into the region **12** of the heat exchange section **1**.

[0100] Thus, when the magnetocaloric effect material generates heat, the amount of heat is selectively provided to the heat transport medium **80***a*. On the other hand, when the magnetocaloric effect material absorbs heat, the amount of heat drawn from the heat transport medium **80***b* can be suppressed. As a result, the generated warm heat can be efficiently sent to the high temperature side heat exchange section **4**.

[0101] In the heat transport medium **9**, in step S**4** in which the magnetocaloric effect material absorbs heat, the heat transport medium **90***a* having a high specific heat per unit volume is fed into the region **13** of the heat exchange section **1**. In step S**2** in which the magnetocaloric effect material generates heat, the heat transport medium **90***b* having a low specific heat per unit volume is fed into the region **13** of the heat exchange section **1**.

[0102] Thus, when the magnetocaloric effect material absorbs heat, the amount of heat is selectively drawn from the heat transport medium **90***a*. When the magnetocaloric effect material generates heat, the amount of heat absorbed from the heat transport medium **90***b* can be suppressed. As a result, the generated cool heat can be efficiently sent to the low temperature side heat exchange section **5**.

Second Embodiment

[0103] FIG. **5** is a schematic view for illustrating a magnetic refrigeration system according to a second embodiment.

[0104] As shown in FIG. **5**, the magnetic refrigeration system **101** includes a heat exchange section **1**, a magnetic field generating section **2**, a moving section **3**, a high temperature side heat exchange section **4**, a low temperature side heat exchange section **5**, a piping **6**, a piping **7**, a heat transport medium **8**, a heat transport medium **9**, a transport section **10**, a transport section **11**, a high temperature side ejecting section **16**, a low temperature side ejecting section **17**, a feeding section **18**, and a control section **34**.

[0105] As in the magnetic refrigeration system **100** described above, the high temperature side heat exchange section **4** performs heat exchange between the heat transport medium **8** heated in the heat exchange section **1** and a heat exchange target, not shown. The low temperature side heat exchange section **5** performs heat exchange between the heat transport medium **9** subjected to heat absorption in the heat exchange section **1** and a heat exchange target, not shown.

[0106] In this case, if the heat transport media **8**, **9** stagnate inside the high temperature side heat exchange section **4** and the low temperature side heat exchange section **5**, the heat exchange efficiency may decrease.

[0107] In the following description, as an example, it is assumed that the heat transport medium **80***a*, **90***a* is liquid (e.g., water) and the heat transport medium **80***b*, **90***b* is gas (e.g., air).

[0108] For instance, the heat transport medium **80***b*, **90***b* being a gas may stagnate inside the high temperature side heat exchange section **4** and the low temperature side heat exchange section **5**. This hampers the inflow of the heat transport medium **80***a*, **90***a* and may decrease the heat exchange efficiency in the high temperature side heat exchange section **4** and the low temperature side heat exchange section **5**. Furthermore, if the temperature of the heat transport medium **80***a* is increased by heating, part of the heat transport medium **80***a* being a liquid is evaporated. Then, the evaporated gas may coexist (suspend) in the heat transport medium **80***a*. In such cases, the phases of the heat transport medium **80***a* and the heat transport medium **80***b* may be mixed. Furthermore, the heat exchange efficiency in the high temperature side heat exchange section **4** may decrease.

[0109] Thus, in this embodiment, a high temperature side ejecting section **16** and a low temperature side ejecting section **17** are provided so that the gas having low contribution to heat exchange is ejected into the atmosphere before flowing into the high temperature side heat exchange section **4** and the low temperature side heat exchange section **5**.

[0110] More specifically, on the inflow side (upstream side) of the high temperature side heat exchange section **4**, a high temperature side ejecting section **16** for ejecting the heat transport medium **80***b* is provided. On the inflow side (upstream side) of the low temperature side heat exchange section **5**, a low temperature side ejecting section **17** for ejecting the heat transport medium **90***b* is provided.

[0111] The high temperature side ejecting section **16** and the low temperature side ejecting section **17** can be e.g. a gas-liquid separator including a gas-liquid separation membrane.

[0112] By providing a high temperature side ejecting section **16** and a low temperature side ejecting section **17**, the above problem can be solved.

[0113] The high temperature side ejecting section **16** and the low temperature side ejecting section **17** illustrated in FIG. **5** are provided separately from the high temperature side heat exchange section **4** and the low temperature side heat exchange section **5**. However, the embodiment is not limited thereto. For instance, the high temperature side ejecting section **16** may be provided inside the high temperature side heat exchange section **4**. The low temperature side ejecting section **17** may be provided inside the low temperature side heat exchange section **5**.

[0114] Furthermore, the heat transport medium **90***a* has a low risk of coexistence of evaporated gas. Thus, the low temperature side ejecting section **17** may be omitted to provide only the high temperature side ejecting section **16**.

[0115] The feeding section **18** reconfigures the heat transport media **8**, **9**.

[0116] For instance, the feeding section **18** allows the heat transport medium **80***b* ejected by the high temperature side ejecting section **16** to be formed again on the outflow side (downstream side) of the high temperature side heat exchange section **4**. Furthermore, the feeding section **18** allows the heat transport medium **90***b* ejected by the low temperature side ejecting section **17** to be formed again on the outflow side (downstream side) of the low temperature side heat exchange section **5**.

[0117] In the case described above, after the heat transport medium **80***a* passes through the high temperature side heat exchange section **4**, the feeding section **18** feeds a prescribed amount of heat transport medium **80***b* into the piping **6** to reconfigure the heat transport medium **8** composed of the heat transport medium **80***a* and the heat transport medium **80***b*. After the heat transport medium **90***a* passes through the low temperature side heat exchange section **5**, the feeding section **18** feeds a prescribed amount of heat transport medium **90***b* into the piping **7** to reconfigure the heat transport medium **9** composed of the heat transport medium **90***a* and the heat transport medium **90***b*.

[0118] More specifically, the feeding section **18** feeds the heat transport medium **80***b* in the same amount as the heat transport medium **80***b* ejected by the high temperature side ejecting section **16**. The feeding section **18** feeds the heat transport medium **90***b* in the same amount as the heat transport medium **90***b* ejected by the low temperature side ejecting section **17**.

[0119] The control section **34** controls the operation of the moving section **3**, the transport section **10**, the transport section **11**, and the feeding section **18**.

[0120] More specifically, when the heat exchange section **1** is fed with the heat transport medium **80***a* and the heat transport medium **90***b*, the control section **34** controls the operation of the moving section **3**, the transport section **10**, and the transport section **11** so as to apply a magnetic field to the heat exchange section **1**. When the heat exchange section **1** is fed with the heat transport medium **80***b* and the heat transport medium **90***a*, the control section **34** controls the operation of the moving section **3**, the transport section **10**, and the transport section **11** so as to remove the magnetic field applied to the heat exchange section **1**. Furthermore, the control section **34** controls the operation of the feeding section **18** so as to reconfigure the heat transport media **8**, **9**.

[0121] Next, the function of the magnetic refrigeration system **101** is illustrated.

[0122] The function of the heat exchange section **1** can be made similar to that illustrated in FIG. **3**.

[0123] More specifically, when a magnetic field is applied to the heat exchange section **1** to cause heat generation, the region **12** is fed with the heat transport medium **80***a* having a high specific heat per unit volume, and the region **13** is fed with the heat transport medium **90***b* having a low specific heat per unit volume.

[0124] As described above, the heat transport medium **90***b* has a lower specific heat per unit volume. Thus, under the same temperature environment, a larger amount of heat generated is absorbed into the heat transport medium **80***a* having a higher specific heat per unit volume. Accordingly, the amount of heat due to heat generation is selectively absorbed into the heat transport medium **80***a*. Thus, the heat transport medium **80***a* is efficiently heated.

[0125] On the other hand, when the magnetic field applied to the heat exchange section **1** is removed to cause heat absorption, the region **12** is fed with the heat transport medium **80***b* having a low specific heat per unit volume, and the region **13** is fed with the heat transport medium **90***a* having a high specific heat per unit volume.

[0126] As described above, the heat transport medium **80***b* has a lower specific heat per unit volume. Thus, under the same temperature environment, a larger amount of heat is drawn to the magnetocaloric effect material from the heat transport medium **90***a* having a higher specific heat per unit volume. Accordingly, heat is selectively drawn to the magnetocaloric effect material from the heat transport medium **90***a*. Thus, the heat transport medium **90***a* is efficiently cooled.

[0127] Then, the heat transport medium **8** (heat transport media **80***a*, **80***b*) is sent to the high temperature side heat exchange section **4**. The heat transport medium **9** (heat transport media **90***a*, **90***b*) is sent to the low temperature side heat exchange section **5**.

[0128] In this case, by the high temperature side ejecting section **16**, the heat transport medium **80***b* is removed before flowing into the high temperature side heat exchange section **4**. By the low temperature side ejecting section **17**, the heat transport medium **90***b* is removed before flowing into the low temperature side heat exchange section **5**.

[0129] In the high temperature side heat exchange section **4**, for instance, heat taken out of the heat transport medium **80***a* can be used for air heating. In the low temperature side heat exchange section **5**, for instance, heat can be absorbed by the heat transport medium **90***a* for air cooling.

[0130] Furthermore, the feeding section **18** reconfigures the heat transport medium **8** on the outflow side (downstream side) of the high temperature side heat exchange section **4**. The feeding section **18** reconfigures the heat transport medium **9** on the outflow side (downstream side) of the low temperature side heat exchange section **5**.

Third Embodiment

[0131] FIGS. **6**A and **6**B are schematic views for illustrating magnetic refrigeration systems according to a third embodiment. More specifically, FIG. **6**A is a schematic view for illustrating a magnetic refrigeration system **100***a* using only heat generation of the magnetocaloric effect material. FIG. **6**B is a schematic view for illustrating a magnetic refrigeration system **100***b* using only heat absorption of the magnetocaloric effect material.

[0132] As shown in FIG. **6**A, the magnetic refrigeration system **100***a* includes a heat exchange section **1**, a magnetic field generating section **2**, a moving section **3**, a high temperature side heat exchange section **4**, a piping **6**, a heat transport medium **8**, a transport section **10**, and a control section **24***a*.

[0133] The control section **24***a* controls the operation of the moving section **3** and the transport section **10**.

[0134] More specifically, when the heat exchange section **1** is fed with the heat transport medium **80***a*, the control section **24***a* controls the operation of the moving section **3** and the transport section **10** so as to apply a magnetic field to the heat exchange section **1**. When the heat exchange section **1** is fed with the heat transport medium **80***b*, the control section **24***a* controls the operation of the moving section **3** and the transport section **10** so as to remove the magnetic field applied to the heat exchange section **1**

[0135] Thus, when the magnetocaloric effect material generates heat, heat can be efficiently absorbed by the heat transport medium **80***a* having a high specific heat per unit volume. When the magnetocaloric effect material absorbs heat, heat drawn to the magnetocaloric effect material by the heat transport medium **80***b* having a low specific heat per unit volume can be suppressed. As a result, the heat exchange efficiency can be improved.

[0136] As shown in FIG. **6**B, the magnetic refrigeration system **100***b* includes a heat exchange section **1**, a magnetic field generating section **2**, a moving section **3**, a low temperature side heat exchange section **5**, a piping **7**, a heat transport medium **9**, a transport section **11**, and a control section **24***b*.

[0137] The control section **24***b* controls the operation of the moving section **3** and the transport section **11**.

[0138] More specifically, when the heat exchange section **1** is fed with the heat transport medium **90***b*, the control section **24***b* controls the operation of the moving section **3** and the transport section **11** so as to apply a magnetic field to the heat exchange section **1**. When the heat exchange section **1** is fed with the heat transport medium **90***a*, the control section **24***b* controls the operation of the moving section **3** and the transport section **11** so as to remove the magnetic field applied to the heat exchange section **1**.

[0139] Thus, when the magnetocaloric effect material generates heat, heat absorbed by the heat transport medium **90***b* having a low specific heat per unit volume is suppressed. When the magnetocaloric effect material absorbs heat, heat is efficiently drawn to the magnetocaloric effect material by the heat transport medium **90***a* having a high specific heat per unit volume. As a result, the heat exchange efficiency can be improved.

[0140] Here, the magnetic refrigeration system **100***a* can also include a high temperature side ejecting section **16** and a feeding section **18** illustrated in FIG. **5**. The magnetic refrigeration system **100***b* can also include a low temperature side ejecting section **17** and a feeding section **18** illustrated in FIG. **5**.

[0141] In the embodiments illustrated above, respective phases of heat transport media different in specific heat per unit volume are formed. The phases of heat transport media thus formed are sequentially fed into the heat exchange section **1**. However, the embodiments are not limited thereto.

[0142] For instance, by using a switching valve and the like, the heat transport medium fed into the heat exchange section **1** may be switched so that heat transport media different in specific heat per unit volume are sequentially fed into the heat exchange section **1**.

[0143] That is, it is only necessary that heat transport media different in specific heat per unit volume be sequentially fed into the heat exchange section **1**.

Practical Example

[0144] Next, a comparison with an AMR magnetic refrigeration system according to a comparative example is described. The comparison is intended to investigate the effect of the magnetic refrigeration system according to the embodiment.

Practical Example 1

[0145] FIGS. **7**A and **7**B are schematic sectional views for illustrating the heat exchange section **1** of the magnetic refrigeration system according to the embodiment. More specifically, FIG. **7**A shows the case of applying a magnetic field. FIG. **7**B shows the case of removing the applied magnetic field.

[0146] The region **14** of the heat exchange section **1** illustrated in FIGS. **7**A and **7**B is formed from a Gd (gadolinium) plate. The weight of the Gd plate was set to 100 g, the z-direction thickness was set to 3 mm, and the x-direction length was set to 115 mm. As the region **12** and the region **13**, linear channels each having a z-direction depth of 3 mm, a y-direction width of 2 mm, and an x-direction length of 115 mm were formed on the Gd plate. In the region **12** and the piping **6** and in the region **13** and the piping **7**, a water phase and an air phase were alternately formed. Furthermore, the water phase and the air phase were made equal in volume ratio. The occupied volume per phase was made equal to the channel volume.

[0147] First, as shown in FIG. **7**A, the water phase was placed in the region **12**, and the air phase was placed in the region **13**. Then, by applying a magnetic field to the heat exchange section **1**, the magnetocaloric effect material (Gd (gadolinium)) was caused to generate heat.

[0148] Next, as shown in FIG. **7**B, the water phase was ejected from the region **12** so that an air phase was placed in the region **12**. Furthermore, the air phase was ejected from the region **13** so that a water phase was placed in the region **13**. Then, by removing the magnetic field applied to the heat exchange section **1**, the magnetocaloric effect material is caused to absorb heat.

[0149] The foregoing process was taken as one cycle. During one cycle, the temperature T_H of air and water flowing through the region **12** was measured by a thermocouple in contact with the air and water in the region **12**. From the temperature change, the weight of the water phase, and the weight of the air phase in this measurement, the amount of heat absorption was determined, and the heat transport efficiency was calculated.

[0150] In this case, the heat transport efficiency was defined by equation (1).

Heat transport efficiency=(Amount of heat absorption of water+Amount of heat absorption of air in region 12)/Theoretical amount of heat generation from Gd (gadolinium) 100 g during magnetic field application of one cycle (1)

[0151] Here, the amount of heat absorption of water is given by specific heat of water (4.2 kJ/kg/K)×density of water (1000 kg/m^3)×volume of region **12** (m^3)×maximum temperature increase of water (ΔT_{H2O}). The amount of heat absorption of air is given by specific heat of air (1 kJ/kg/K)×density of air (1.29 kg/m^3)×volume of region **12** (m^3)×temperature increase of air (ΔT_{air}). The theoretical amount of heat generation from Gd 100 g during magnetic field application of one cycle (QGd) was determined by QGd=T (298 K)×magnetic entropy change (ΔS=2.5 kJ/kg/K)×0.1 (kg−Gd).

Comparative Example 1

[0152] FIG. **8** is a schematic sectional view for illustrating a heat exchange section **51** of the AMR magnetic refrigeration system according to the comparative example.

[0153] First, 100 g of Gd (gadolinium) particles having the magnetocaloric effect with a diameter of 1 mm were packed in a cylindrical container **52** having an inner diameter of 15 mm and a length of 115 mm with a packing ratio of 60%. At the end portion, a partition plate **53** made of a metal mesh was provided. Then, the remaining space inside the heat exchange section **51** was filled with water to produce a heat exchange section **51**.

[0154] To the heat exchange section **51**, a magnetic field having the same intensity as that of Practical example 1 was applied to cause the Gd (gadolinium) particles to generate heat.

[0155] Then, the partition plate **53** was moved +1 cm in the X-axis direction to move the water. The moving speed was set to 0.4 cm/s.

[0156] Next, the applied magnetic field was removed. After the removal, the partition plate **53** was moved −1 cm in the X-axis direction to move the water. The moving speed was set to 0.4 cm/s.

[0157] The foregoing process was taken as one cycle. During one cycle, the temporal change of the temperature of water was measured by a thermocouple placed in the water. From the temperature change and the weight of water, the heat transport efficiency during heat generation was calculated.

[0158] In this case, the heat transport efficiency was calculated using the following equation (2).

Heat transport efficiency=Amount of heat absorption of water/Theoretical amount of heat generation from Gd 100 g during magnetic field application of one cycle (2)

[0159] Here, the amount of heat absorption of water is given by specific heat of water (4.2 kJ/kg/K)×density of water (1000 kg/m^3)×filling volume of water in cylindrical container **52** (m^3)×maximum temperature increase of water (ΔT_{H2O}). The theoretical amount of heat generation from Gd 100 g during magnetic field application of one cycle (QGd) was determined by QGd=T (298 K)×magnetic entropy change (ΔS=2.5 kJ/kg/K)×0.1 (kg−Gd).

[0160] FIG. **9** is a graph showing the comparison between the heat transport efficiency in Practical example 1 and the heat transport efficiency in Comparative example 1.

[0161] With regard to the temperature measurement, the initial temperature of water and the initial temperature of air were set to 25° C., equal to the ambient temperature.

[0162] As shown in FIG. 9, the heat transport efficiency in Practical example 1 was 50%, and the heat transport efficiency in Comparative example 1 was 2.6%. That is, it was confirmed that Practical example 1 achieved a significantly higher heat transport efficiency than Comparative example 1.

[0163] The embodiments described above can realize a magnetic refrigeration system capable of improving the heat transport efficiency.

[0164] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions. Moreover, above-mentioned embodiments can be combined mutually and can be carried out.

[0165] For instance, the shape, dimension, material, layout and the like of various components in the magnetic refrigeration system **100**, the magnetic refrigeration system **101**, the magnetic refrigeration system **100*a***, the magnetic refrigeration system **100*b*** and the like are not limited to those illustrated above, but can be appropriately modified.

What is claimed is:

1. A magnetic refrigeration system comprising:

a first heat exchange section including a magnetocaloric effect material;

a magnetic field changing section configured to change magnetic field to the first heat exchange section;

a first heat transport medium;

a second heat transport medium separated from the first heat transport medium and being different from the first heat transport medium in specific heat per unit volume; and

a transport section configured to sequentially feed the first heat exchange section with the first heat transport medium and the second heat transport medium.

2. The system according to claim **1**, wherein

the transport section feeds the first heat exchange section with the first heat transport medium having a higher specific heat per unit volume than the second heat transport medium, and

the magnetic field changing section applies the magnetic field to the first heat exchange section to cause the heat exchange section to generate heat.

3. The system according to claim **1**, wherein

the transport section feeds the first heat exchange section with the first heat transport medium having a higher specific heat per unit volume than the second heat transport medium, and

the magnetic field changing section removes the magnetic field applied to the first heat exchange section to cause the heat exchange section to absorb heat.

4. The system according to claim **1**, wherein

the first heat exchange section includes a first region and a second region configured to pass the heat transport media,

when the first region is fed with the first heat transport medium, the second region is fed with the second heat transport medium, and

when the first region is fed with the second heat transport medium, the second region is fed with the first heat transport medium.

5. The system according to claim **1**, wherein one of the first heat transport medium and the second heat transport medium is liquid, and the other is gas.

6. The system according to claim **1**, further comprising:

a second heat exchange section configured to perform heat exchange between the first heat transport medium flowing out of the first heat exchange section and a heat exchange target.

7. The system according to claim **6**, further comprising:

an ejecting section configured to eject the second heat transport medium to outside on inflow side of the second heat exchange section; and

a feeding section configured to feed the second heat transport medium from outside on outflow side of the second heat exchange section.

8. The system according to claim **7**, wherein

the first heat transport medium is liquid,

the second heat transport medium is gas, and

the ejecting section includes a gas-liquid separation membrane.

9. The system according to claim **7**, wherein the feeding section feeds the second heat transport medium in a same amount as the second heat transport medium ejected by the ejecting section.

10. The system according to claim **1**, wherein the magnetocaloric effect material includes at least one selected from the group consisting of Gd (gadolinium), a Gd compound, an intermetallic compound made of various rare earth elements and transition metal elements, a Ni_2MnGa alloy, a GdGeSi compound, a $LaFe_{13}$-based compound, and $LaFe_{13}H$.

11. The system according to claim **1**, wherein the magnetic field changing section includes a magnetic field generating section and a moving section configured to change relative position of the first heat exchange section and the magnetic field generating section.

12. The system according to claim **1**, wherein the magnetic field changing section includes an electromagnet and a switch configured to switch between energization and deenergization of the electromagnet.

13. The system according to claim **6**, further comprising:

a piping connecting the first heat exchange section, the second heat exchange section, and the transport section in a closed loop.

14. The system according to claim **1**, wherein the first heat transport medium and the second heat transport medium are separated from each other.

15. The system according to claim **1**, wherein the first heat transport medium and the second heat transport medium are one of gas, liquid, and solid.

16. The system according to claim **1**, wherein the second heat transport medium is air or nitrogen gas.

17. The system according to claim **1**, wherein the first heat transport medium is at least one selected from the group consisting of water, an oil-based medium, and a solvent-based medium.

18. The system according to claim **13**, wherein the transport section circulates the first heat transport medium and the second heat transport medium in a channel formed in a closed loop.

* * * * *