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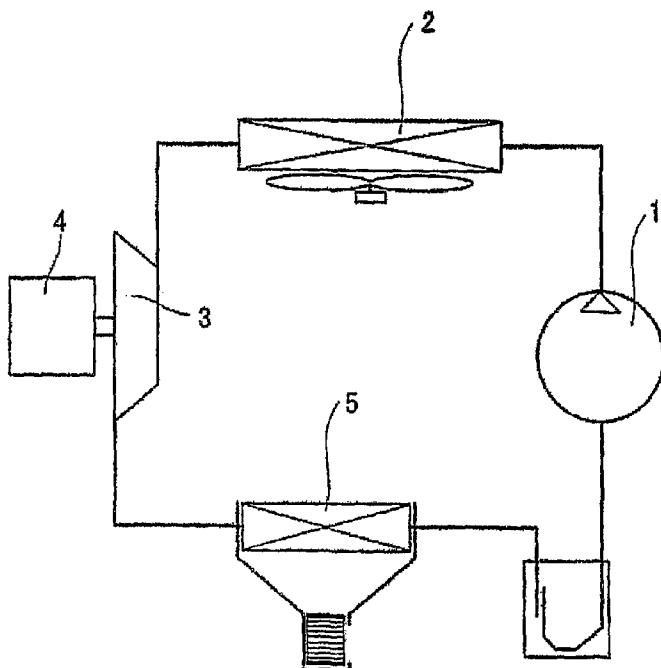
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(54) Title: REFRIGERATING APPARATUS



(57) Abstract: A refrigerating apparatus includes a compressor, a gas cooler, an expander for recovering expansion energy of a refrigerant, and an evaporator, all of which are connected in series to define a refrigeration cycle. The refrigerant is mixed with non-condensation gas such as nitrogen.

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DESCRIPTION

Refrigerating Apparatus

5 Technical Field

The present invention relates to a refrigerating apparatus and, in particular but not exclusively, to a refrigerating apparatus having an expander for recovering expansion energy of a refrigerant.

Background Art

10 In recent years, a power recovery refrigeration cycle has been proposed to further enhance the efficiency of a refrigeration cycle. According to Japanese Laid-Open Patent Publication No. 2000-329416, an input of a compressor is reduced by recovering expansion work of a refrigerant using an expander. The expander for use in the power recovery refrigeration cycle is disclosed in, for
15 example, Japanese Laid-Open Patent Publication No.2004-257303.

Fig. 4 depicts a conventional refrigerating apparatus as disclosed in Japanese Laid-Open Patent Publication No. 2000-329416, which includes a compressor 1, a gas cooler (or radiator) 2, an expander (or expansion unit) 3, and an evaporator 5, all connected in series to define a refrigeration cycle. The
20 expander 3 is coupled to a generator 4. The compressor 1 is driven by a driving means (not shown) such as, for example, an electric motor or an engine. A refrigerant is compressed by the compressor 1 from an ordinary temperature and low pressure state to a high temperature and high pressure state, and is subsequently cooled by the gas cooler 2 to an ordinary temperature and high
25 pressure state. Thereafter, the refrigerant expands in the expander 3 to a low temperature and low pressure state, and is then heated by the evaporator 4 to the ordinary temperature before the refrigerant returns to the compressor 1 again. The expander 3 recovers expansion work of the refrigerant to drive the generator 4,

thereby generating electric power.

Fig. 5 depicts a Mollier diagram of the conventional refrigerating apparatus. In the expander 3, the refrigerant expands within a short period of time of being 10ms to 20ms and, hence, this process can be regarded as adiabatic expansion wherein the enthalpy of the refrigerant reduces along an isentropic line (c → d). Accordingly, as compared with the case where an expansion valve is used to merely cause an isenthalpic change without any expansion work, a specific enthalpy difference in the evaporator 5 increases by expansion work Δi_{exp} , making it possible to increase the refrigeration capacity. Also, the expander 3 can allow the generator 4 to generate electric power from the expansion work Δi_{exp} of the refrigerant, and the electric power required for driving the compressor 1 can be reduced by supplying the electric power to the compressor 1. As described hereinabove, an increase in refrigeration capacity of the evaporator 5 and a reduction in electric power for driving the compressor 1 can enhance COP (Coefficient of Performance) of the refrigerating apparatus.

As is clear from Fig. 5, in the expander 3 used in the refrigerating apparatus, the refrigerant is in a single-phase state at an inlet (c) and in a two-phase (gas-liquid) state at an outlet (d) and, hence, a phase change occurs in the expansion process.

Fig. 6 is a graph indicating a relationship between the volume and pressure of a working chamber in the expander that is used in the conventional refrigerating apparatus as disclosed in Japanese Laid-Open Patent Publication No.2004-257303. In the first half of the expansion process, the pressure drop with respect to the volume change is large because the supercritical phase or liquid phase refrigerant (single phase refrigerant) similar to an incompressible fluid expands, while in the second half of the expansion process, the pressure drop with respect to the volume change is small because the refrigerant undergoes a phase change from a liquid phase to a gas phase and expands largely while reducing the

pressure and temperature thereof.

It is generally known that when nucleate boiling takes place within refrigerant tubes mounted in the evaporator 5 of the refrigerating apparatus of Fig. 4, a phase change occurs on heat transfer surfaces of the refrigerant tubes, and that the phase change is affected by the surface shape of or a heat flux on the heat transfer surfaces. However, because the phase change of the refrigerant in the expander 3 occurs along the isentropic line shown in Fig. 5 during adiabatic expansion, there is no heat flux from the heat transfer surfaces, and because the wall surface of the working chamber is formed smooth for reduction of flow loss and mechanical loss, the phase change occurs from the inside of the refrigerant as well as the wall surface. In order to create bubble nucleuses inside a fluid, a superheat liquid is needed that stores up energy by virtue of having a temperature greater than a saturation temperature. However, a phase change delay occurs during the process of producing the superheat liquid. The phase change delay reduces the expansion rate of the refrigerant, giving rise to a reduction in expansion work of the refrigerant recovered by the expander 3.

The present invention has been developed to overcome the above-described disadvantages.

It is accordingly an objective of the present invention to provide a high-efficiency refrigerating apparatus capable of preventing the phase change delay.

Disclosure of the Invention

In accomplishing the above and other objectives, the refrigerating apparatus according to the present invention includes a compressor, a gas cooler, an expander for recovering expansion energy of a refrigerant, and an evaporator, all connected in series to define a refrigeration cycle, wherein non-condensation gas is mixed in the refrigerant.

By this construction, the non-condensation gas mixed in the refrigerant

acts to create bubble nucleuses that cause a phase change within the refrigerant in the expander, making it possible to prevent a phase change delay and provide a high efficiency refrigerating apparatus.

Preferably, the non-condensation gas has a boiling point less than —
5 40°C. Even if the refrigerating apparatus according to the present invention is used for hot-water supply or heating in cold areas, such non-condensation gas can be used with an ample margin, thus increasing the effect of preventing the phase change delay.

Advantageously, nitrogen is employed as the non-condensation gas.
10 Nitrogen is relatively inexpensive and can be obtained with ease.

Again advantageously, the non-condensation gas has a concentration less than or equal to 1.0wt%.

The refrigerating apparatus may include a fluid agitator mounted at an inlet of the expander. The fluid agitator acts to turn bubbles of the
15 non-condensation gas mixed in the refrigerant into small bubbles to increase the number of bubble nucleuses for the phase change, thereby increasing the effect of preventing the phase change delay.

It is preferred that carbon dioxide be employed as the refrigerant. The use of carbon dioxide can increase a pressure difference between high and low
20 pressures in the refrigerating apparatus, and the use of non-condensation gas can prevent the phase change delay that has been hitherto caused in the conventional refrigerating apparatus employing only carbon dioxide as the refrigerant.

Brief Description of the Drawings

The above and other objectives and features of the present invention
25 will become more apparent from the following description of a preferred embodiment thereof with reference to the accompanying drawings, throughout which like parts are designated by like reference numerals, and wherein:

Fig. 1 is a graph indicating a relationship between a load coupled to an

expander and a speed of rotation of the expander;

Fig. 2 is a graph indicating a relationship between the temperature of carbon dioxide at an inlet of the expander and the efficiency of the expander;

Fig. 3 is a graph indicating a relationship between the temperature of carbon dioxide at the inlet of the expander and COP of a refrigeration cycle;

Fig. 4 is a schematic view of a refrigerating apparatus according to the present invention and a conventional refrigerating apparatus.

Fig. 5 is a Mollier diagram of the conventional refrigerating apparatus; and

Fig. 6 is a graph indicating a relationship between the volume and the pressure of a working chamber of the expander that is used in the conventional refrigerating apparatus.

Detailed Description of the Preferred Embodiment

It is first to be noted that although the refrigerating apparatus of Fig. 4 has been described as being a conventional one, it is also applicable to the present invention. That is, a refrigerating apparatus according to the present invention includes a compressor 1, a gas cooler or radiator 2, an expander or expansion unit 3, and an evaporator 5, all connected in series to define a refrigeration cycle. The refrigerating apparatus according to the present invention also includes a generator 4 coupled to the expander 3. The refrigerating apparatus according to the present invention differs from the conventional refrigerating apparatus in that the former employs a refrigerant in which non-condensation gas has been mixed.

The non-condensation gas is always maintained in a gaseous state irrespective of the state (pressure and temperature) of the refrigerant. The non-condensation gas is defined as a substance having a condensing temperature less than a minimum temperature of the refrigerant during operation of the refrigerating apparatus. Because the non-condensation gas is always in a gaseous state, even if the refrigerant is in a liquid state, the non-condensation gas in the

expander 3 becomes bubble nucleuses that act to cause a phase change inside the refrigerant, making it possible to prevent the aforementioned phase change delay from taking place. Other factors required for the non-condensation gas are: very low reactivity and solubility with and in the refrigerant; and no influence on the refrigerant. Regarding the volume of the non-condensation gas mixed in the refrigerant, if the volume is too much, the properties of the refrigerant are deteriorated, followed by a reduction in performance of the refrigeration cycle, while if the volume is too small, the number of bubble nucleuses existing in the refrigerant reduces, followed by a reduction in the effect of preventing the phase change delay.

Accordingly, the volume of the non-condensation gas is appropriately determined.

<Example>

Experiments were conducted wherein carbon dioxide was employed as a refrigerant that circulates through the refrigeration cycle, and 1.0wt% nitrogen employed as the non-condensation gas was mixed in the refrigerant.

Nitrogen has a boiling point of -195.8°C under atmospheric pressure and a critical point of -147.0°C at 3.4MPa. Accordingly, nitrogen is always in a gaseous state at temperatures greater than -40°C , at which carbon dioxide is maintained in ordinary refrigeration cycles. The reactivity and solubility of nitrogen with and in carbon dioxide are both very low.

The experiments were conducted using the refrigeration cycle of Fig. 4. The refrigeration cycle was first evacuated, filled with nitrogen of 100g, and then filled with carbon dioxide of 10kg employed as the refrigerant. A swing expander having a suction volume of 11.8cc was employed as the expander 3.

Figs. 1 to 3 are graphs indicating the results of the experiments. In the Figures, "NC-1" denotes a case where 1.0wt% nitrogen was mixed in carbon dioxide, and "without NC-1" denotes a case where pure carbon dioxide was used as the refrigerant. In Fig. 1, the abscissa indicates a load (W) coupled to the expander 3, while the ordinate indicates the speed of rotation (rpm) of the expander.

3. For example, when the speed of rotation of the expander 3 was about 1800rpm, "NC-1" could increase the load from 200W to 300W. When the speed of rotation of the expander 3 was about 900rpm, "NC-1" could increase the load from 900W to 1000W. That is, the graph of Fig. 1 reveals that addition of 1.0wt% nitrogen can
5 increase the electric power that is generated by the generator 4 coupled to the expander 3.

Fig. 2 is a graph indicating a relationship between the temperature of carbon dioxide at an inlet of the expander 3 and the efficiency of the expander 3. This graph reveals that addition of 1.0wt% nitrogen can increase the efficiency of
10 the expander 3 throughout the entire temperature range in which the experiments were conducted.

Fig. 3 is a graph indicating a relationship between the temperature of carbon dioxide at the inlet of the expander 3 and COP of the refrigeration cycle. The COP is a coefficient of performance defined by a ratio of the quantity of
15 refrigeration capacity obtained by the evaporator 5 to the electric power inputted to the compressor 1 upon subtraction of the electric power recovered by the expander 3. The larger the COP value is, the higher the efficiency of the refrigeration cycle is. Fig. 3 reveals that addition of 1.0wt% nitrogen can increase the COP and the efficiency of the refrigeration cycle throughout the entire temperature range in which
20 the experiments were conducted. According to additional experiments, addition of 1.0wt% or less nitrogen to the refrigerant is preferred.

As is clear from the above, the efficiency of the expander and the COP of the refrigeration cycle can be increased by mixing a non-condensation gas in a refrigerant.

25 It is to be noted here that although in the above-described embodiment the expander 3 has been described as being coupled to the generator 4, a shaft (not shown) of the expander 3 may be aligned with and connected to a shaft (not shown) of the compressor 1.

Also, the expander 3 may be provided with a fluid agitator in the form of a mesh or bar inserted in the inlet thereof. The fluid agitator acts to turn bubbles of the non-condensation gas mixed in the refrigerant into small bubbles to increase the number of bubble nucleuses for the phase change, thereby increasing the effect of preventing the phase change delay and providing a high-efficiency refrigerating apparatus.

It is further to be noted that although in the above-described embodiment a swing expander is employed as the expander 3, any displacement type expander such as, for example, a scroll expander, a rolling piston expander, a sliding vane expander, or the like may be employed.

It is also to be noted that the non-condensation gas is not limited to nitrogen, and rare gas such as argon, neon or the like may be used.

Although the present invention has been fully described by way of examples with reference to the accompanying drawings, it is to be noted here that various changes and modifications will be apparent to those skilled in the art. Therefore, unless such changes and modifications otherwise depart from the spirit and scope of the present invention, they should be construed as being included therein.

Industrial Applicability

The refrigerating apparatus according to the present invention is not limited to freezers or refrigerators, but it can be applicable to ordinary air conditioners, heat pump apparatuses for hot-water supply, and the like.

CLAIMS

1. A refrigerating apparatus comprising a compressor, a gas cooler, an expander for recovering expansion energy of a refrigerant, and an evaporator, all connected in series to define a refrigeration cycle, wherein non-condensation gas is
5 mixed in the refrigerant.
2. The refrigerating apparatus according to claim 1, wherein the non-condensation gas has a boiling point less than -40°C .
3. The refrigerating apparatus according to claim 2, wherein nitrogen is employed as the non-condensation gas.
- 10 4. The refrigerating apparatus according to any one of claims 1 to 3, wherein the non-condensation gas has a concentration less than or equal to 1.0wt%.
5. The refrigerating apparatus according to any one of claims 1 to 4, further comprising a fluid agitator mounted at an inlet of the expander.
- 15 6. The refrigerating apparatus according to any one of claims 1 to 5, wherein carbon dioxide is employed as the refrigerant.

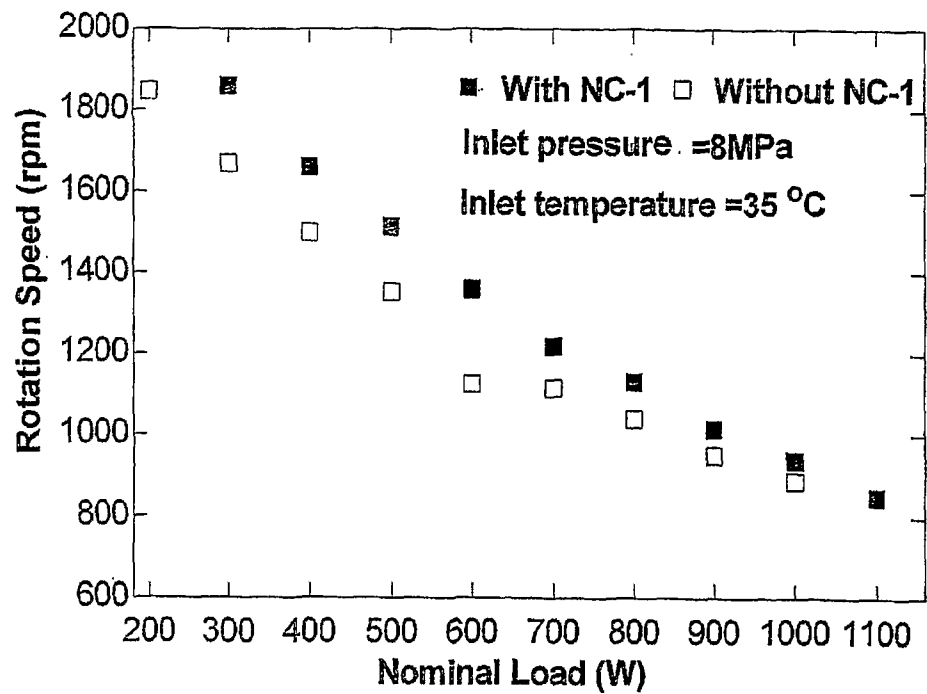
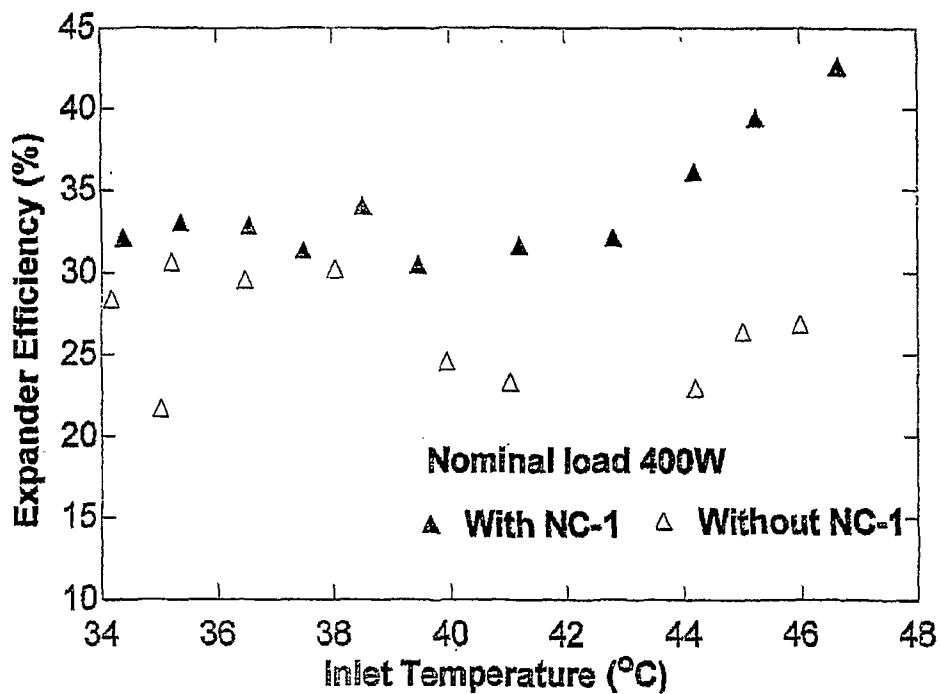
Fig. 1*Fig. 2*

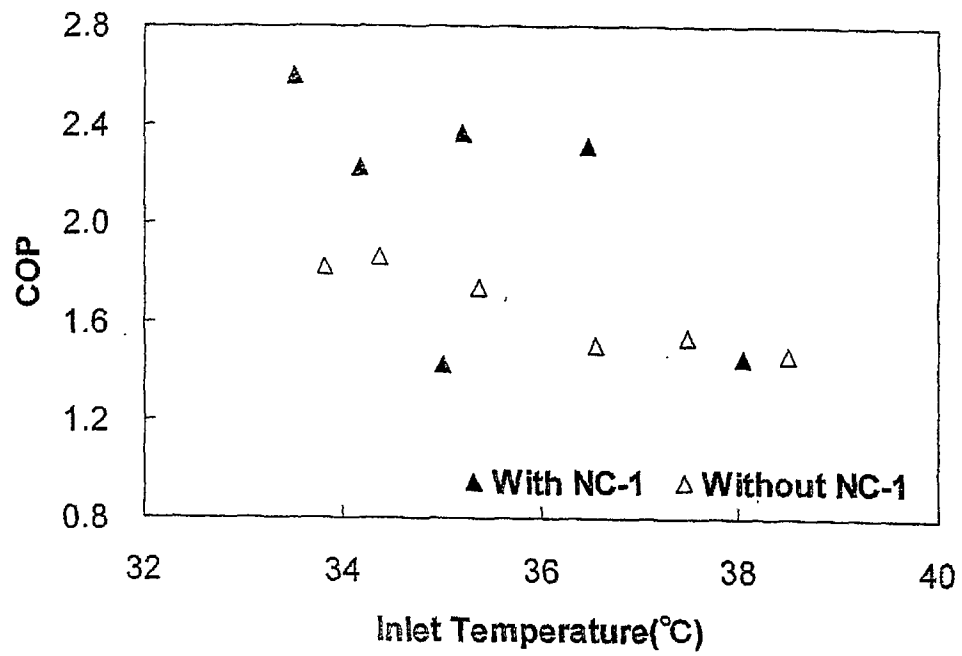
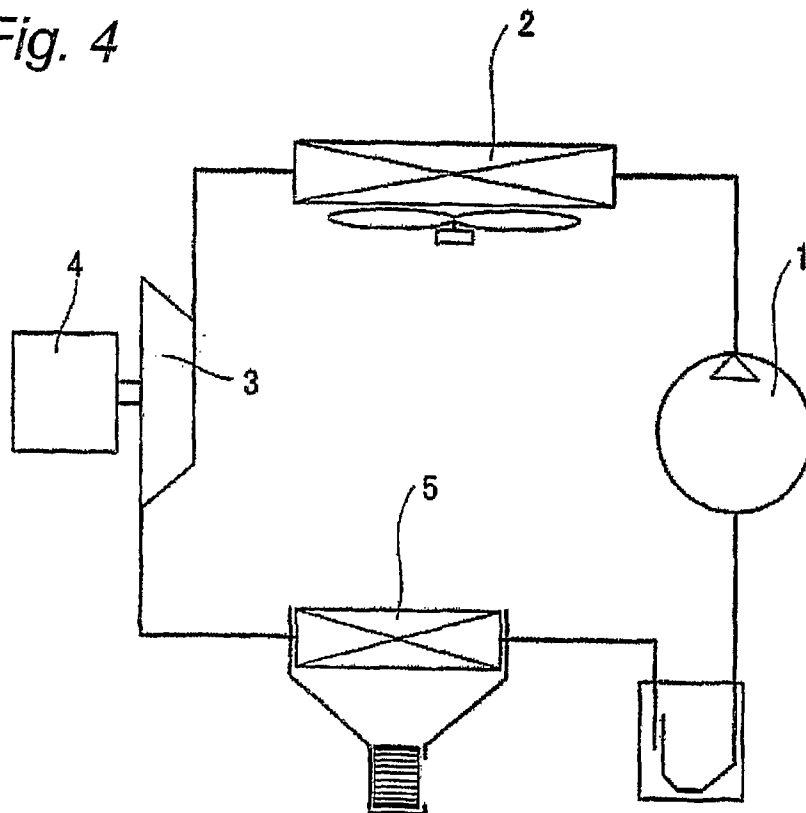
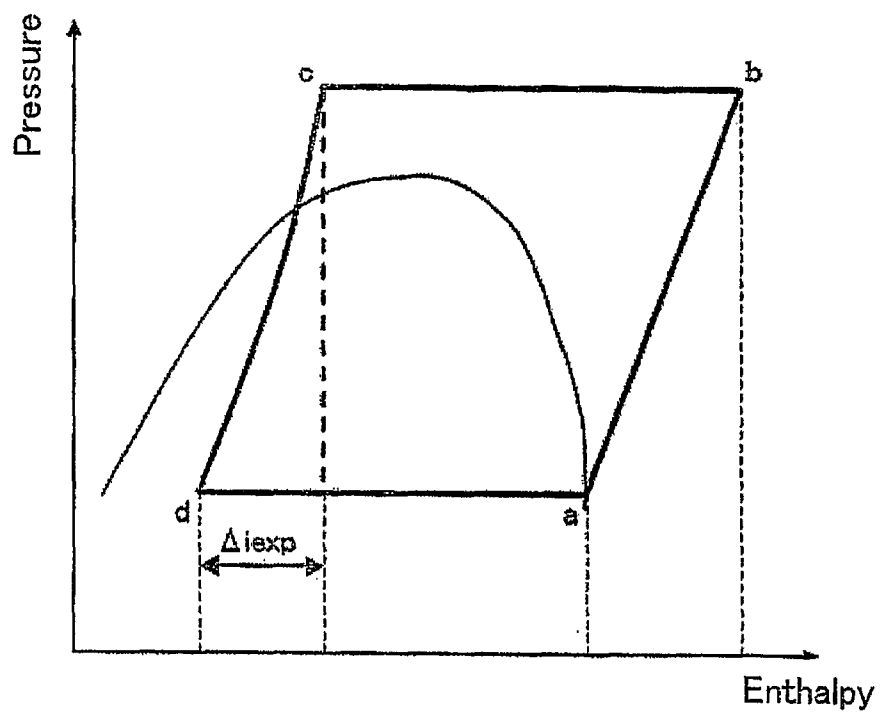
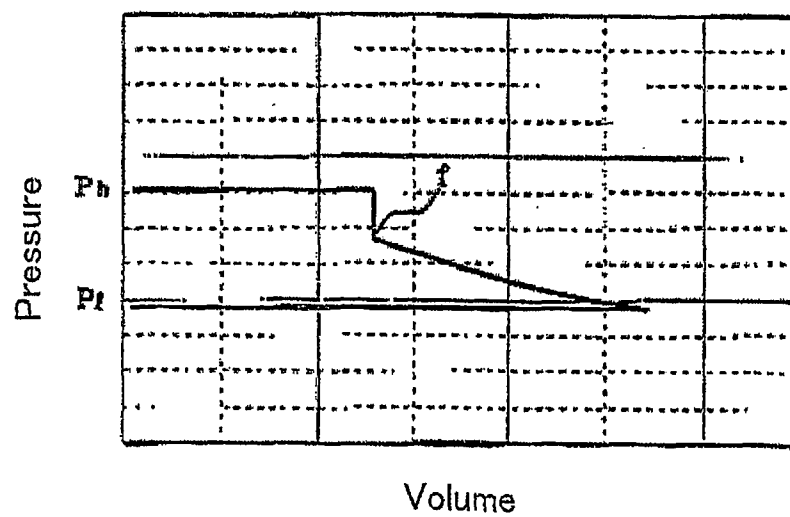
Fig. 3*Fig. 4*

Fig. 5*Fig. 6*

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER		
IPC ⁷ F25B 9/00		
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)		
IPC ⁷ F25B F25D		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Chinese patents, CAJ fulltext database		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
WPI, EPODOC, PAJ		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN, A, 1207803 (KONVEKTA AG) 10.Feb. 1999 (10.02.1999) Whole document	1-6
A	CN, A, 1564925 (SINVENT AS) 12.Jan. 2005 (12.01.2005) Whole document	1-6
A	US, A, 4175400 (ROVAC CORP) 27.Nov. 1979 (27.11.1979) Whole document	1-6
A	DE, A, 4302474 (HOCHHAUS KARL HEINZ DR ING et al) 11.Aug. 1994 (11.08.1994) Whole document	1-6
☐ 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		
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PCT/CN2005/001142

CN, A, 1207803	10.Feb. 1999 (10.02.1999)	WO, A, 9727437	31.Jul. 1997 (31.07.1997)
		AU, A, 4482496	20.Aug. 1997 (20.08.1997)
		EP, A, 0876576	11.Nov. 1998 (11.11.1998)
		DE, D, 19681212	11.Mar. 1999 (11.03.1999)
		BR, A, 9612461	13.Jul. 1999 (13.07.1999)
		DE, D, 59604923	11.May. 2000 (11.05.2000)
		US, A, 6085544	11.Jul. 2000 (11.07.2000)
		JP, T, 2000515958	28.Nov. 2000 (28.11.2000)
CN, A, 1564925	12.Jan. 2005 (12.01.2005)	WO, A, 03021164	13.Mar. 2003 (13.03.2003)
		CA, A, 2459276	13.Mar. 2003 (13.03.2003)
		TW, B, 565678	11.Dec. 2003 (11.12.2003)
		EP, A, 1427972	16.Jun. 2004 (16.06.2004)
		BR, A, 0212276	19.Oct. 2004 (19.10.2004)
		ZA, A, 200401723	24.Nov. 2004 (24.11.2004)
		US, A, 2004255609	23.Dec. 2004 (23.12.2004)
		JP, T, 2005502022	20.Jan. 2005 (20.01.2005)
US, A, 4175400	27.Nov. 1979 (27.11.1979)	DE, A, 2757303	24.Aug. 1978 (24.08.1978)
		JP, A, 53104936	12.Sep. 1978 (12.09.1978)
		FR, A, 2381250	15.Sep. 1978 (15.09.1978)
		US, A, 4175397	27.Nov. 1979 (27.11.1979)
		US, A, 4175398	27.Nov. 1979 (27.11.1979)
		US, A, 4175399	27.Nov. 1979 (27.11.1979)
		GB, A, 1566412	30.Apr. 1980 (30.04.1980)
		CA, A, 1116424	19.Jan. 1982 (19.01.1982)
		IT, B, 1089798	18.Jun. 1985 (18.06.1985)
DE, A, 4302474	11.Aug. 1994 (11.08.1994)	None	