(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 691 039 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
16.08.2006 Bulletin 2006/33

(51) Int Cl.:
F01K 25/08 ***(2006.01)*** ***F01K 25/04*** ***(2006.01)***
F01K 23/08 ***(2006.01)*** ***F01K 7/32*** ***(2006.01)***

(21) Application number: **05101039.5**

(22) Date of filing: **11.02.2005**

(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 MC NL PL PT RO SE SI SK TR
Designated Extension States:
AL BA HR LV MK YU

(71) Applicant: **Blue Sky Energy N.V.**
Curaçao (AN)

(72) Inventor: **Hoos, Frank**
3271 AH, Mijnsheerenland (NL)

(74) Representative: **Aalbers, Arnt Reinier**
De Vries & Metman
Overschiestraat 180
1062 XK Amsterdam (NL)

(54) Process and apparatus for generating work

(57) The invention pertains to an apparatus a process of generating work comprising the steps of expanding a gas, preferably substantially adiabatically and/or at the critical pressure and temperature of the gas, causing part of the gas to condensate and form a liquid phase, and separating, during or after expansion, at least part of the liquid phase from the gas phase. This process facilitates generating work at a relatively high efficiency.

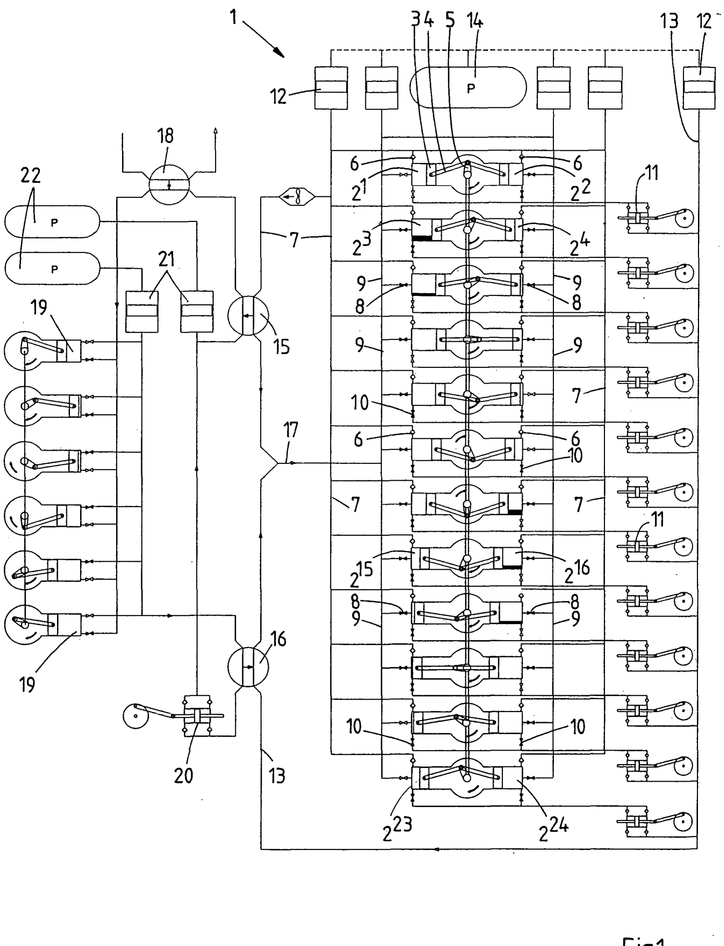

Fig.1

EP 1 691 039 A1

Description

[0001] The invention relates to a process and an apparatus for generating work.

[0002] In current power plants, work is typically generated by means of a Carnot cycle, also referred to as "steam cycle", employing a high temperature source and a low temperature source. In practice, a high temperature medium, typically superheated steam, is fed to a turbine, which generates work, and is subsequently condensed, (super)heated and once more fed to the turbine. I.e., the difference between the amount of heat contained in the high temperature medium and the amount of heat sunk to the low temperature source is converted into work, in accordance with the first law of thermodynamics.

[0003] At higher temperature differences between the high and low temperature sources, more heat can be converted into work and the efficiency of the process improves. Typically, the environment (earth) serves as the low temperature source (heat sink) and the high temperature medium is generated by burning fossil fuels or by nuclear fission.

[0004] It is an object of the present invention to provide a process for generating work at a relatively high efficiency.

[0005] To this end, the process according to the present invention comprises the steps of expanding a gas, preferably substantially adiabatically and/or at the critical pressure and temperature of the gas, causing part of the gas to condensate and form a liquid phase, and separating, during or after expansion, at least part of the liquid phase from the gas phase.

[0006] Thus, a temperature difference and a substantial difference in heat content between the liquid and the gas phase can be generated with little work, preferably by subsequently compressing the gas phase, causing the temperature of the gas phase to increase to a temperature higher, preferably at least 20°C higher, than that of the liquid phase.

[0007] The said differences in temperature and heat content can be employed to generate substantial amounts of work, as will be explained in more detail below.

[0008] A preferred process further comprises the step of raising the pressure of the separated liquid.

[0009] It is further preferred that the process comprises the steps of heating a further medium by means of the gas phase and generating work by expanding the further medium, preferably in a Carnot or steam cycle.

[0010] The invention further pertains to an apparatus for producing work comprising at least one cylinder of turbine for expanding a gas, preferably substantially adiabatically and/or at the critical pressure and temperature of the gas, thus causing part of the gas to condensate and form a liquid phase, and means for separating, during or after expansion, at least part of the liquid phase from the gas phase.

[0011] It is preferred that the apparatus further comprises a compressor for compressing the gas phase, preferably substantially adiabatically or cooled, causing the temperature of the gas phase to increase to a temperature higher, preferably at least 20°C higher, than that of the liquid phase. Consequently, a substantial difference in heat content between the liquid and the gas phase can be generated with little work.

[0012] It is further preferred that the said components form a main cycle for generating a relatively low temperature liquid and a relatively high temperature gas and that the cycle is coupled to a further cycle for generating work.

[0013] The invention will now be explained in more detail with reference to the drawings, which schematically show a presently preferred embodiment.

[0014] Figure 1 is a schematic layout of a power plant in accordance with the present invention.

[0015] Figures 2A to 2C show cross-sections of a preferred cylinder and piston assembly suitable for use in the power plant of Figure 1.

[0016] Figure 3 shows a side view and a cross-section of a preferred centrifuge for separating liquid and gas at the outlet of the assembly of Figures 2A to 2C.

[0017] Identical parts and parts performing the same or substantially the same function will be denoted by same numeral.

[0018] Figure 1 shows a layout of a power plant 1 including two systems, a first system operated in accordance with the present invention and referred to as "heat swing cycle" and a second system operated in accordance with a Carnot or steam cycle.

[0019] In this example, the first system comprises twelve pairs of cylinders 2^1 - 2^{24}, each cylinder 2 containing a piston 3 connected, via a rod 4, to a common crankshaft 5. This particular crankshaft 5 is modular, i.e. it comprises a crank section for each pair of cylinders 2 interconnected by means of e.g. pre-tensioned splines (not shown). Thus, the total power of the plant 1 can be de- or increased by respectively removing or adding (pairs of) cylinders 2.

[0020] Each cylinder 2 comprises a non-return valve 6, connected to a gas pressure line 7 and allowing gas to be expelled from the cylinder 2, and a control valve 8, connected to a suction line 9 and allowing fluid to be drawn into the cylinder 2. A further control valve 10 is provided to remove liquid from the cylinder 2. The further control valves 10 of each pair of cylinders 2 are connected to a pump 11.

[0021] The gas pressure lines 7 are mutually interconnected and in communication with compensators 12 to reduce pulsations in the lines 7. The same is true for the suction lines 9 and the liquid pressure lines 13 of the pumps 11, i.e. these lines 9, 13, are interconnected and connected to respective compensators 12. The compensators 12 in turn are connected to a common pressure vessel 14 and serve to equalise pulsations generated by the cylinders 2. Further, the gas pressure lines 7 and liquid pressure lines 13 are connected to respectively first and second reverse current heat exchangers 15, 16, and, downstream from the heat exchangers 15, 16, connected to a central (collecting) duct 17, which in turn is connected to the suction lines 9.

[0022] The second system, referred to as "steam cycle", comprises an evaporator, i.e. the first heat exchanger 15, a condenser, i.e. the second heat exchanger 16, an additional heater 18, and a heat engine, known in itself and comprising, in this example, a plurality of piston generators 19, and a pump 20, which serves as a boiler feed pump. The system further comprises, downstream from both the heat engine 19 and the pump 20, compensators 21, which are connected to common pressure vessels 22.

[0023] During start-up, the heat swing system is filled, for example, with Argon, whereas the Carnot cycle is filled, for example, with CF_4. Both systems are cooled to a temperature preferably at least 50 °C lower than ambient temperature, e.g. to 150 K, and the pressure and temperature in the heat swing system are controlled to be substantially equal to the critical pressure (P_c) and temperature (T_c) of the medium, in this example, Argon. At or close to the critical pressure and temperature the heat swing cycle will be at its most efficient.

[0024] During operation, each of the cylinders goes through a cycle comprising the following steps:

- Expanding the gas substantially adiabatically (shown in uneven cylinder 2^1; and even cylinder 2^{12}), generating work and causing the greater part of the gas to condensate and form a liquid phase (cylinders 2^3, 2^5). As mentioned, it is preferred that the gas is in its critical state (P_c, T_c) at the start of the expansion cycle. Typically, over 50% of the gas is converted to liquid.
- Removing, at the end of the expansion stroke of the piston, the liquid phase from the cylinder by means of the corresponding liquid pump (cylinder 2^7). Alternatively, the liquid is removed during the expansion stroke.
- Compressing the remaining gas to a pressure slightly higher than the system pressure (preferably P_c), thus expelling substantially all of the gas from the cylinder, and to a temperature significantly higher than the starting temperature (uneven cylinders 2^9 - 2^{19}).
- Charging gas into the cylinder, again preferably at the critical pressure and temperature (cylinders 2^{21}, 2^{23}), thus generating work. The volume charged into the cylinder is substantially equal to the initial volume (cylinder 2^1).

[0025] The gas expelled from the cylinders is fed to the first reverse current heat exchanger, i.e. heat of the gas is used to heat condensate in the steam cycle. Further, the temperature of the gas is decreased to T_c or near T_c.

[0026] Upon removal from the cylinders after expansion, the liquid pressure is increased to P_c by use of the pumps. As the compressibility of the liquid is very low, an increase in pressure will substantially not result in an increase of the liquid temperature. Subsequently, the liquid is fed to the second heat exchanger, i.e. the heat content of the (relatively cold) liquid is used to convert gas in the condensers of the steam cycle to liquid. Further, the temperature of the liquid in the heat swing cycle is increased to T_c or near T_c.

[0027] The heated liquid and cooled gas in the heat swing cycle are subsequently mixed to obtain a mixture having a pressure and temperature substantially equal to the pressure and temperature of the mixture that was present in the cylinder at the start of the expansion stroke (shown in uneven cylinder 2^1; and even cylinder 2^{12}).

[0028] The steam cycle is operated thus: The medium, e.g. CF_4, in the steam cycle is pre-heated in the evaporator 15 and, since the amount of heat is not sufficient to completely evaporate the medium, subsequently heated in the additional heater 18, which preferably comprises a heat exchanger that absorbs heat from the environment, such as a river or the atmosphere. The heated medium is fed to the heat engine, where it generates work, and discharged to the condenser 16, where the medium is cooled and condensed by means of the liquid in the heat swing cycle. Finally, the medium is pumped to the evaporator 15 and the cycle is complete.

[0029] As thermal losses result in a relatively low efficiency, all equipment described above and indeed any auxiliary equipment is thermally isolated in a manner known in itself.

[0030] If the same type of fluid, e.g. Argon, is used in both the heat swing- and steam cycles, it is preferred that the gas in the heat swing cycle is cooled during compression. Such cooling can be achieved e.g. with the cold condensate after it has been used for gas to liquid conversion in the condenser of the steam cycle.

[0031] Figures 2A to 3 show a preferred cylinder and piston assembly 25 suitable for use in the power plant 1 of Figure 1 and a preferred centrifuge 26 for separating liquid and gas at the outlet of this assembly 25.

[0032] The assembly 25 comprises two pistons 3, rigidly interconnected by means of a rod 4 and received inside corresponding cylinders 2. At its centre, the rod 27 is provided with a slot 28 extending in a direction substantially perpendicular to the direction of reciprocating movement of the pistons 3 and allowing a crank of a crankshaft 5 to pass. The pistons 3 are connected to the crankshaft 5 by means of respective pairs of rods 29A, 29B. The cylinders 2 each comprise a spiral cylinder head 30 having a tangential outlet 31 and an axial inlet duct 32. The inlet duct 32 is fixed with respect to the cylinder head 30 and slidingly received in a central bore 33 in the piston 3. Furthermore, the piston 3 itself comprises a plurality of return ducts 34 that extend substantially parallel to the central bore 33 and open, via vanes 35, into the spiral cylinder head 30.

[0033] Figure 3 shows an active cyclone 26 for separating the gas and the liquid and comprising an inlet 40, connected to the tangential outlet 31 of the cylinder 2, a central rotor 41 having a plurality of U-shaped ducts 42, an annular filter 43 surrounding the outlets of the ducts 42 and providing an annular outlet duct 44 for the liquid, and, beneath the filter 43, an annular outlet duct 45 for collecting the gas.

[0034] During operation, a gas, preferably at its critical pressure and temperature, is continuously fed, via the inlet duct 32 to one of the cylinders 2 and allowed to expand, causing the piston to move towards the crankshaft and causing part of the medium to condensate, forming a liquid phase. Furthermore, the piston will cause the piston in the other (opposite) cylinder, which is in a different stage of the cycle, to compress the medium contained in that cylinder. The medium containing the condensate subsequently flows through the return ducts 34 and passed the vanes 35, which impart a centrifugal force on the condensate and entrain droplets. The flow is then fed to the inlet 41 of the cyclone 26 and separated into a liquid (outlet 44) and a gas (outlet 45).

[0035] Compared to the cylinders discussed with respect to Figure 1, the assembly according to Figures 2A to 3 more readily allows continuously separating the liquid, during expansion, from the gas.

[0036] The invention will now be illustrated by way of a numerical example. The calculations below are based on the following assumptions and conditions: the pistons move without friction, the process is considered to be adiabatic and reversible (isentropic), heat can be transferred at negligible differential temperatures, and the flow of the media is constant (no pulsations). The starting temperature (T_h) of the medium in the heat swing cycle, Argon, is 150 K (-123°C) and the temperature after expansion (T_l) is 110 K (-163°C). Work inputted (W_{inp}) in the heat swing cycle to compress the medium amounts to 1000 kJ.

[0037] During expansion, part of the medium condensates thus forming a liquid. The heat withdrawn from the liquid (the low temperature source) is calculated by:

$$\left(\frac{1}{1-\frac{T_l}{T_h}}\right)\cdot W_{inp}=\left(\frac{T_h}{T_h-T_l}\right)\cdot W_{inp}=3.75\cdot 1000kJ=3750kJ$$

[0038] The heat added to the gas (the high temperature source) is calculated by

$$\left(\frac{T_h}{T_h-T_l}\right)\cdot W_{inp}=3750kJ$$

[0039] Adding the work inputted in the system yields a total amount of heat of 3750 + 1000 = 4750 kJ.

[0040] The exergy of the system is 4750 - 3750 = 1000 kJ, which is the work inputted to complete the cycle. However, the energy of the total system will be much higher if environmental heat is used as a high temperature source in the steam cycle.

[0041] The efficiency factor of heat to work conversion in such a cycle with an environmental temperature of 275 K (2°C) is defined as:

$$1-\frac{T_l}{T_h}=\frac{T_h-T_l}{T_h}=\frac{275-110}{275}=0.6$$

[0042] The amount of heat required from the high temperature source (e.g. a river) is:

$$\frac{1}{1-0.6}*3750kJ=9375kJ$$

[0043] The amount of work that can be derived from the steam cycle is:

$$Q_h - Q_c = 9375 - 3750 = 5625kJ$$

[0044] The amount of heat available in the high temperature source is 4750 kJ. The amount of heat withdrawn from the environment is 9375 - 4750 = 4625 kJ. The amount of work generated in the steam cycle is calculated at 5625 kJ. However, it took 1000 kJ to sustain the heat swing cycle. So the total result is 5625 - 1000 = 4625 kJ, not surprisingly the same amount, as the amount withdrawn from the environment.

[0045] The heat swing efficiency factor amounts to

$$\frac{W_{out}}{W_{in}} = \frac{4625}{1000} = 4.625$$

[0046] It is noted that this is a calculated factor, which will be lower in an actual power plant.

[0047] The invention is not restricted to the above-described embodiments, which can be varied in a number of ways within the scope of the claims. For instance, instead of cylinder and piston assemblies, the heat swing cycle can be operated using rotary converters. Also, the gas and the liquid can be separated by means of a filter or electrostatically.

Claims

1. Process for generating work comprising the steps of
expanding a gas, preferably substantially adiabatically and/or at the critical pressure and temperature of the gas, causing part of the gas to condensate and form a liquid phase, and
separating, during or after expansion, at least part of the liquid phase from the gas phase.

2. Process according to claim 1, comprising the step of subsequently compressing the gas phase, preferably substantially adiabatically or cooled, causing the temperature of the gas phase to increase to a temperature higher, preferably at least 20°C higher, than that of the liquid phase.

3. Process according to claim 1 or 2, comprising the step of raising the pressure of the separated liquid.

4. Process according to claim 2 or 3, wherein the pressure of the separated liquid and the gas is raised to the critical pressure of the medium.

5. Process according to any one of the preceding claims, comprising the steps of
heating a further medium by means of the gas phase, generating work by expanding the further medium.

6. Process according to claim 5, comprising the step of, after heating a further medium by means of the gas phase, heating the further medium with environmental heat.

7. Process according to claim 5 or 6, wherein work is generated with the further medium by means of a Carnot or steam cycle.

8. Process according to claim 7, wherein the liquid phase is evaporated by means of the further medium.

9. Process according to any one of the preceding claims, comprising the step of bringing the medium, prior to expanding, at or near its critical pressure and temperature.

10. Process according to any one of the preceding claims, wherein, at all the said steps, the medium has a temperature lower than ambient temperature, preferably lower than -100°C.

11. Process according to any one of the preceding claims, wherein the medium respectively the further medium is

selected from the group consisting of Argon and Nitrogen, respectively from the group consisting of CF_4 and methane.

12. Process according to any one of the preceding claims, wherein the gas phase and a liquid phase are separated by means of centrifuging or filters or electrostatically.

13. Apparatus (1) for producing work comprising
at least one cylinder (2) or turbine for expanding a gas, preferably substantially adiabatically and/or at the critical pressure and temperature of the gas, thus causing part of the gas to condensate and form a liquid phase, and
means (10, 11; 26) for separating, during or after expansion, at least part of the liquid phase from the gas phase.

14. Apparatus (1) according to claim 13, comprising a compressor (2) for compressing the gas phase, preferably substantially adiabatically or cooled, causing the temperature of the gas phase to increase to a temperature higher, preferably at least 20°C higher, than that of the liquid phase.

15. Apparatus (1) according to claim 13 or 14, wherein the said components (2, 10, 11; 26) are part of a main cycle for generating a relatively low temperature liquid and a relatively high temperature gas and wherein the cycle is coupled to a further cycle (15, 18, 19, 16) for generating work.

16. Apparatus (1) according to claim 15, wherein the further cycle comprises a heat exchanger (18) to absorb heat from the environment.

17. Apparatus (1) according to claim 16, wherein the further cycle comprises an evaporator (15), which is thermally coupled to the high temperature gas (7) in the main cycle, a condenser (16), thermally coupled to the low temperature liquid (12) in the main cycle, and a heat engine (19).

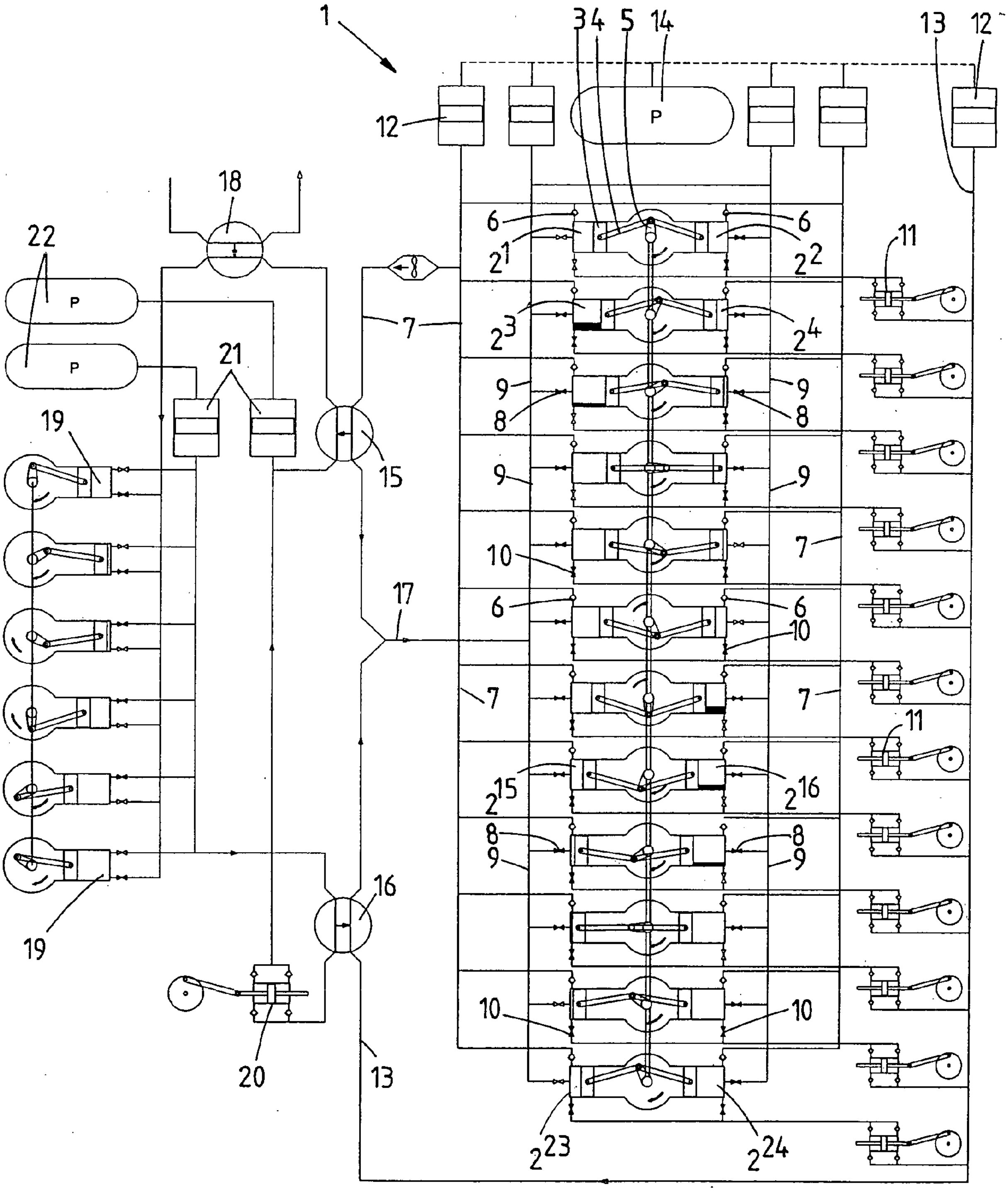
1
3
4
5
14
13
12
12
P
18
22
P
P
21
6
6
2^1
2^2
11
7
2^3
2^4
9
9
8
8
19
15
9
9
10
7
6
6
17
10
7
7
11
2^15
2^16
8
8
9
9
19
16
10
10
20
13
2^23
2^24

Fig.1

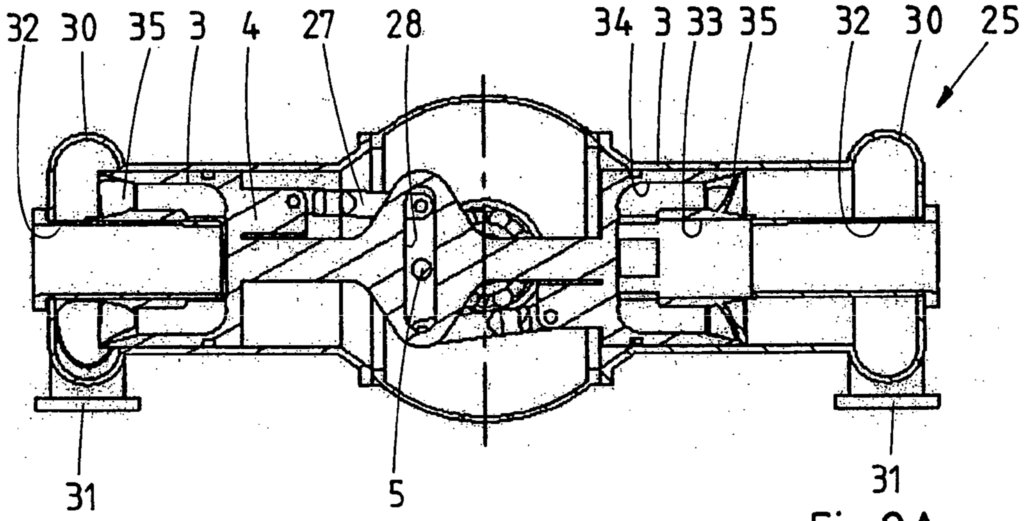

Fig.2A

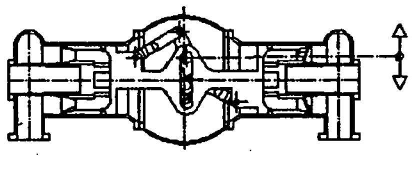

Fig.2B

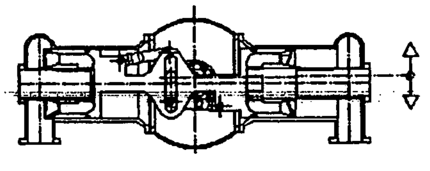

Fig.2C

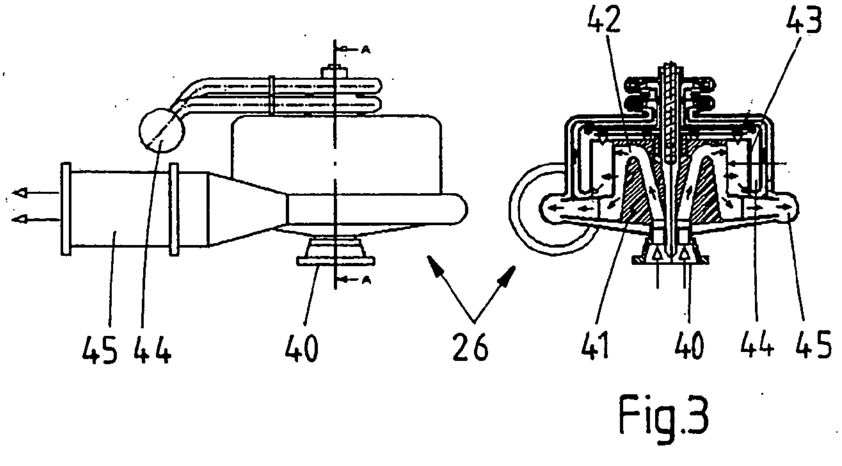

Fig.3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 05 10 1039

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	PATENT ABSTRACTS OF JAPAN vol. 010, no. 246 (M-510), 23 August 1986 (1986-08-23) & JP 61 076707 A (HISAKA WORKS LTD), 19 April 1986 (1986-04-19) * abstract *	1,3,13	F01K25/08 F01K25/04 F01K23/08 F01K7/32
X	EP 0 485 596 A (TSELEVOI NAUCHNO-TEKHNICHESKY KOOPERATIV "STIMER") 20 May 1992 (1992-05-20) * column 2, line 16 - column 5, line 28; figures; examples 1,2 * * abstract *	1,13	
X	US 5 525 034 A (HAYS ET AL) 11 June 1996 (1996-06-11) * column 7, line 14 - line 62; figure 8 * * abstract *	1,3,13	
X	US 2004/144093 A1 (HANNA WILLIAM THOMPSON ET AL) 29 July 2004 (2004-07-29) * paragraph [0025] * * paragraph [0041] - paragraph [0043]; figure 2A * * abstract *	1,13	TECHNICAL FIELDS SEARCHED (Int.Cl.7) F01K
A	US 5 806 316 A (AVAKOV ET AL) 15 September 1998 (1998-09-15) * column 3, line 33 - column 6, line 52; figures * * abstract *	11	
A	GB 2 338 034 A (* LANNANET LTD) 8 December 1999 (1999-12-08) * abstract *	11	
E	WO 2005/031123 A (CITY UNIVERSITY; SMITH, IAN, KENNETH) 7 April 2005 (2005-04-07) * the whole document *	1-17	

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	27 October 2005	Zerf, G

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 05 10 1039

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

27-10-2005

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
JP 61076707	A	19-04-1986	JP	1830278	C	15-03-1994
			JP	5035242	B	26-05-1993
EP 0485596	A	20-05-1992	AU	4650689	A	24-08-1990
			WO	9008882	A1	09-08-1990
US 5525034	A	11-06-1996	WO	9623129	A1	01-08-1996
			US	5385446	A	31-01-1995
US 2004144093	A1	29-07-2004	NONE			
US 5806316	A	15-09-1998	AU	4267893	A	29-11-1993
			CA	2134777	A1	11-11-1993
			CN	1080986	A	19-01-1994
			DE	69301657	D1	04-04-1996
			DE	69301657	T2	24-10-1996
			EP	0638138	A1	15-02-1995
			WO	9322541	A1	11-11-1993
			JP	7506163	T	06-07-1995
GB 2338034	A	08-12-1999	NONE			
WO 2005031123	A	07-04-2005	NONE			

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82