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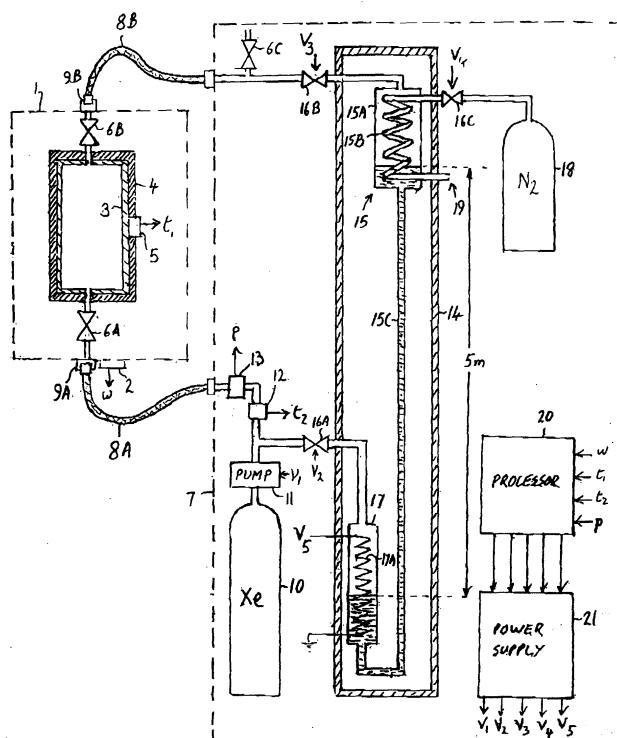
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(54) **Filling a container with gas under pressure**

(57) When filling a tank with xenon or krypton gases for use as a propellant in satellites, it is necessary to proceed slowly to allow heat to dissipate. The invention deals with this problem by withdrawing gas from the tank, cooling it, and re-introducing the cooled gas into the tank. The circulation of gas from and back to the tank is preferably achieved by a thermosyphonic action. The

gas is preferably liquefied when it is cooled to give a strong thermosyphonic action and may be evaporated again before being returned to the tank.

In a variation of the invention, the temperature of the tank is prevented from falling below a critical minimum temperature during depressurization of the tank by recirculating and heating some of the fluid during depressurization.



Description

[0001] This invention relates to the filling of a container with gas under pressure. It arose when considering certain problems associated with existing methods of pumping xenon or krypton gases into reservoirs in satellites. These gases are used as propellants in electric propulsion systems used for manoeuvring Earth-orbiting satellites into their final orbital position. The gases are stored in the satellite at high pressure (typically 200-300 bars) at a temperature higher than their critical point so that they remain in entirely gaseous form.

[0002] To minimize risks associated with handling a pressurized reservoir, it is normally filled with the pressurized propellant gas at the latest possible time in the satellite's launch preparation phase, just before its installation on the launcher. During the filling process it may be necessary to exclude personnel from the area for safety reasons. This prevents other activities being performed during the filling process and consequently the time taken for filling has a direct repercussion on the time taken for the firing programme. It is therefore necessary to reduce the time taken for the filling of the reservoir as much as possible. This need is especially acute when it is intended to launch a constellation of satellites at closely spaced time intervals.

[0003] The speed of filling of the reservoir is limited by thermal heating caused by compression of the gas. A high temperature, typically above 60°C, may be incompatible with the materials employed for the construction of the reservoir and adjacent equipment and would limit the mass of gas that could be accommodated at a given maximum pressure.

[0004] It is therefore necessary to fill the reservoir sufficiently slowly to allow heat to dissipate. However, dissipation of the heat may be hampered by thermally insulating properties of the material (typically carbon/alloy) from which the reservoir is made; and by thermal insulation applied to the surface of the reservoir. Dissipation of heat also relies on the slow process of natural convection to transfer heat from the gas into the skin of the reservoir.

[0005] Proposals for shortening the filling process have included temporarily removing the insulation from the reservoir to allow it to cool more rapidly. However this may be difficult when the reservoir is incorporated in the satellite's structure. Another proposal was to provide a cooling system using ducts for cooling fluid around the external surface of the reservoir. However, accessibility difficulties meant that only a fraction of the external surface of the reservoir is made accessible to the cooling system. Also, the use of a cooling system would have required the addition of non-removable components to the satellite's structure. These additional components would be redundant when the satellite is in flight and would have had a negative effect on the weight, performance and reliability of the satellite. Also, the effectiveness of the cooling system would be limited

by the need to avoid cooling the surface of the reservoir below a specified temperature, typically 15-20°C. If the temperature were brought below that level in an endeavour to achieve rapid cooling of the gaseous content of the reservoir, there would be a risk that condensation of humidity from the air would form on the surface of the reservoir and drip onto neighbouring electronic equipment, causing damage.

[0006] Another proposal involved the installation, inside the reservoir, of a coiled pipe through which water or cold nitrogen would be passed. However, this would seriously increase the weight of the reservoir and would introduce design, cost and reliability problems because of the need for additional high pressure sealed penetrations of the reservoir skin. Such penetrations need to be carefully designed and constructed so as to remain reliable over long periods even when subjected to high thermal gradients and thermal shocks.

[0007] According to the invention it is proposed that, in a method of pressurizing fluid in a container, the maximum temperature caused by the pressurization be controlled by withdrawing fluid from the container, cooling it, and re-introducing the cooled fluid into the container.

[0008] The invention also provides an apparatus for filling a container with fluid under pressure comprising a compressor and a first connector for connecting the output of the compressor to the container, characterized by a second connector for withdrawing fluid from the container, a cooling arrangement for cooling the withdrawn fluid and means for returning the cooled fluid into the container.

[0009] It will readily be understood that by employing the invention it is possible efficiently to remove heat caused by the pressurization of fluid propellant into a tank in a satellite or other vehicle using cooling equipment which is entirely located outside the vehicle so that it can be detached after the filling operation is completed and does not affect the efficiency or weight of the vehicle. The fluid may thus be pressurized by a pump located outside the vehicle, pass into the container through a detachable inlet connection, be withdrawn from the container through a detachable outlet connection, and be cooled by a cooling arrangement located outside the vehicle before being re-introduced into the container through the aforementioned inlet connection. It may be an advantage for the inlet and outlet connections to be separated from each other, preferably at different ends of the container, so that the circulation of fluid through the cooling arrangement causes some disturbance or turbulence inside the tank to ensure that the fluid inside the container is at a substantially uniform temperature.

[0010] In a preferred arrangement in accordance with the invention, the fluid is fed through flexible lines to detachable inlet and outlet connections of the container. This allows an assembly comprising the pump, source of fluid and cooling arrangement to be moved to a location close to the container, to be connected easily to it using flexible connections, and to be detached and re-

moved after the container is filled. A particular advantage of arrangements having flexible hoses is that it enables the container (or the entire vehicle on which the container is mounted) to be weighed to give an indication of the amount of fluid loaded into it. An alternative technique would be to weigh the source of the fluid, preferably together with the cooling arrangement which will also contain some fluid.

[0011] It will be appreciated that the invention allows the fluid inside the container to be cooled without in any way interfering with thermal insulation which may be carried on the surface of the container since the cooling effect achieved by the invention does not rely on conduction through the walls of the container.

[0012] Preferably the fluid withdrawn from the container is cooled sufficiently to increase its density significantly, and the arrangement is such that the density difference between warm and cool fluid causes the fluid to circulate around a circuit passing through the container and the cooling system. This thermosyphonic arrangement is considered particularly advantageous since no moving parts make contact with the fluid, minimizing the risk of introducing contaminants into the fluid. The cooled fluid is preferably collected in a pipe or column extending vertically or at least having a vertical component of length. The degree of thermosyphonic pressure produced in this way can be controlled by controlling the temperature of the cooler since the density of the cooled fluid will depend on its temperature. It may be necessary to heat the fluid after it passes from the bottom of the pipe or column so that the fluid re-introduced into the container is not so cold as to risk causing condensation.

[0013] The thermosyphonic action described above could be used in an arrangement where the fluid remains in the same state (preferably gaseous) at all parts of the circuit. However, a stronger thermosyphonic action is obtained in an arrangement where the fluid changes from a gas to a liquid when cooled. Liquefied gas, collecting in the pipe or column previously mentioned, can provide a hydrostatic pressure providing a stronger circulatory effect than if the fluid remains in gaseous form. When the gas is liquefied, it is preferably revaporized by heating after passing from the bottom of the pipe or column.

[0014] It has been mentioned that it may be desirable to heat the fluid after passing from the bottom of the pipe or column that provides the thermosyphonic or hydrostatic pressure. The heater provided for this purpose can have an additional use when it is desired to remove the fluid from the reservoir, this being frequently necessary for testing purposes in the case of propellant reservoirs in satellites. When allowing the fluid to escape from the container, care must be taken to ensure that the temperature of the tank does not fall below the minimum specified threshold, because of the danger, previously mentioned, arising from condensation. By recirculating and heating some of the fluid it is possible to speed up the discharge process without allowing the temperature

to drop below this threshold. This technique is considered to be of value, independently of the cooling system and thus according to another aspect of the invention there is provided a method or apparatus for depressurizing fluid in a container characterized in that the minimum temperature caused by the depressurization is controlled by heating some fluid released from the container and re-introducing the heated fluid into the container.

[0015] One way of performing the invention will now be described, by way of example, with reference to the accompanying drawing which illustrates, in a very schematic form and with its different parts not shown to scale, a method of filling a propellant tank in a satellite with pressurized gaseous xenon.

[0016] Referring to the drawing, the illustrated system is designed to meet a requirement to fill a tank for propellant, mounted on a satellite, with 290 kg of xenon at a pressure of no greater than 200 Bars and without allowing the temperature to rise above 60°C. A further requirement is that the temperature of the exterior surface of the tank should not fall below 20°C so as to avoid condensation which might damage the material of the tank.

[0017] In the drawing, a satellite indicated schematically by the broken line 1 rests on a weight sensor 2 producing an output signal w indicating the total weight of the satellite, including the weight of propellant. The propellant is contained within a tank 3 which is designed to withstand a pressure of 200 Bars. The tank carries insulation 4 and the temperature of the outside surface of the tank is monitored by a temperature sensor 5 which produces an output signal t_1 .

[0018] The tank has an inlet and an outlet which can be closed by manual control valves 6A, 6B respectively.

[0019] In the drawing, the satellite 1 is shown linked to a mobile service station 7 by flexible hoses 8A and 8B. These flexible hoses are linked to the satellite by quick release connectors 9A, 9B.

[0020] The mobile service station 7 contains a bottle 10 of xenon. This is not shown to scale and in practice will be much larger than the tank 3. The outlet of the xenon bottle is connected to the input of a pump 11 which may be a mechanical compressor but is preferably embodied as a thermal compressor to avoid the introduction of pollutants caused by moving mechanical parts. The rate of pumping of the compressor 11 is controlled by a signal v_1 and compressed xenon gas at its output is passed to the flexible hose 8A via a temperature sensor 12 (producing an output signal t_2) and a pressure sensor 13 (producing an output signal p).

[0021] The mobile service station 7 also includes a cooling system comprising: an evacuated chamber 14; a condenser 15 located in the chamber 14 and connected to receive xenon gas from the flexible hose 8B; and electrically operated valves 16A, 16B and 16C controlled by respective control signals v_2 , v_3 and v_4 . The output of the condenser is linked by a vertical pipe 15C to

an evaporator 17. The output of the evaporator 17 is connected via the electrically operated valve 16A to join hot gas at the output of the pump 11.

[0022] The condenser 15 comprises a housing 15A and a coiled tube 15B. Nitrogen from a bottle 18 is allowed to pass into the coiled tube via a valve 16C, which is controlled by an electrical control signal v_4 . The cold nitrogen cools the xenon entering the condenser so that the xenon liquefies; and the nitrogen is then vented at 19.

[0023] Signals w , t_1 , t_2 and p are applied to a processor 20 which controls various outputs v_1 to v_5 of a power supply 21.

[0024] Operation of the illustrated system is as follows. Firstly, the mobile service station 7 is moved into a position close to the satellite which is assumed to be in its final stages of preparation prior to assembly in the launching vehicle. The hoses 8A and 8B are connected using the quick release connections 9A and 9B. The power supply 21 is then switched on causing the pump 11 to begin pumping xenon into the tank 3. If the tank 3 initially contains air, it will be necessary to purge this air out by leaving the quick release connection 9A disconnected for an initial period.

[0025] During the pumping operation a portion of the gaseous xenon is removed, via the flexible hose 8B and the valve 16B, and is cooled and liquefied in the condenser 15. The liquefied xenon fills the vertical pipe 15C and part of the housing 15A of the condenser. This liquid is evaporated in the evaporator 17, located at a lower level than the condenser. In the evaporator 17 is located a heater 17A which is supplied with a variable voltage v_5 . The variable voltage v_5 is controlled so as to raise the temperature of the xenon to above its critical point. The xenon therefore evaporates but is still considerably cooler than the contents of the tank 3. This cooled xenon then passes through the valve 16A to a point where it joins the output of the pump 11 and is returned to the tank 3.

[0026] In operation fluid is circulated around the loop, between the tank 3, the condenser 15 and the evaporator 17, by the hydrostatic pressure of approximately 5m of liquid in the vertical pipe 15C. The circulation can be increased or decreased by controlling the valve 16C and therefore the temperature and density of the liquefied xenon in the pipe 15C.

[0027] If the output t_2 , indicative of the temperature of the gas entering the tank, is close to the upper limit of 60°C, signal v_5 (which is a variable voltage) may be reduced, though it cannot be reduced to a level below that at which sufficient heat is provided to vaporize the liquid xenon. Further control is provided by increasing the voltage v_4 so as to increase the flow of nitrogen and therefore the density of the liquid in the column 15C. The circulation through the cooling system is thus increased, causing the temperature of the gas entering the tank to be lowered.

[0028] If the output p of the pressure sensor 13 ap-

proaches 200 Bars, the voltage v_1 is reduced so as to reduce the pumping rate of the compressor 11.

[0029] When the signal w from weight sensor 2 indicates that the required weight of xenon has been introduced into the tank, the processor switches off the power supply 21, resulting in valves 16A, 16B and 16C closing. The manual control valves 6A, 6B are then closed and the flexible hoses 8A, 8B are disconnected, using the quick release connections 9A, 9B. The tank is then ready to supply xenon to a propulsion system of the satellite through a connection (not shown) to the pipe between the tank 3 and the valve 6B.

[0030] The use of the evacuated chamber 14 allows much lower temperatures to be employed than are necessary when the tank is to be filled with xenon and allows the equipment to be used for filling tanks with krypton, which requires a lower temperature for liquefaction. When a mixture of xenon and krypton is to be used it is necessary to maintain the temperature at a level between the critical temperature of krypton and the temperature of the triple point of xenon (161K) to prevent solidification of the xenon.

[0031] Benefit from the invention can be achieved without liquefying the fluid. In this case the cooler 15 will serve to cool the gas so that it has a higher density in the column 15c than in the rest of the system. This will cause circulation around the loop by a thermosyphonic action, though the pressure will not be as great as when liquefaction occurs.

[0032] The illustrated system is also of value in circumstances when it is desired to discharge the pressurized fluid from the tank 3 as is frequently necessary for testing purposes. This discharge process can be performed more quickly than has previously been possible, without allowing the temperature of the tank 3 to drop below the limit of 15°C to 20°C. For this purpose valves 6A, 6B and 6C are partially opened, allowing some of the gas to be vented to atmosphere through 6C whilst a proportion, already at a cold temperature as a result of expansion through valve 6B, is pushed through the condenser 15 and vertical pipe 15C to the evaporator 17. The voltage v_5 , in this mode of operation, is controlled so as to raise the temperature to a level above that of the gas entering the condenser, before being returned to the tank 3 via valve 6A. In this way the temperature of the tank is maintained above its minimum permissible level.

Claims

1. A method of pressurizing fluid in a container (3) characterized in that the maximum temperature caused by the pressurization is controlled by withdrawing fluid from the container (3), cooling it, and re-introducing the cooled fluid into the container (3).
2. A method according to claim 1 characterized in that

the container (3) is carried by a movable vehicle (1), and in that the fluid: is pressurized by a pump (11) located outside the vehicle (1); passes into the container (3) through a detachable inlet connection (9A); is withdrawn from the container (3) through a detachable outlet connection (9B); is cooled by a cooling arrangement (15) located outside the vehicle (1); and is re-introduced into the container (3) through the inlet connection (9A).

3. A method according to claim 2 characterized in that the fluid is fed through flexible lines (8A, 8B) to the detachable inlet connection (9A) and from the detachable outlet connection (9B).

4. A method according to claim 3 characterized in that an indication of the amount of fluid in the container (3) is obtained by sensing a change in weight as the container (3) is filled.

5. A method according to claim 3 characterized in that an indication of the amount of fluid in the container (3) is obtained by sensing the change in weight of the vehicle or of an assembly comprising a source (10) of the fluid to be pressurized and the cooling arrangement (14).

6. A method according to any preceding claim characterized in that the container (3) is a tank for propellant located in a space vehicle (1).

7. A method according to any preceding claim characterized in that the container (3) carries thermal insulation (4).

8. A method according to any preceding claim characterized in that the fluid is circulated to and from a cooling system (15) by thermosyphonic action.

9. A method according to any preceding claim in which the fluid is cooled sufficiently to liquefy it.

10. A method according to claim 8, or claim 9 when dependent on claim 8, characterized in that the rate of flow of fluid withdrawn from and re-introduced into the container (3) is controlled by regulating the temperature and thus the density of the cooled fluid.

11. A method according to claim 10 characterized in that the fluid is heated before being re-introduced into the container.

12. A method according to claim 11, when dependent on claim 9, characterized in that the fluid is heated sufficiently to revaporize it.

13. A method according to claim 11 or 12 characterized in that the temperature of the fluid re-introduced into

the container (3) is controlled by regulating the heating of the fluid.

14. Apparatus for filling a container with fluid under pressure comprising a compressor (11) and a first connector (9A) for connecting the output of the compressor to the container, characterized by a second connector (9B) for withdrawing fluid from the container, a cooling arrangement (15, 18) for cooling the withdrawn fluid and means (16A, 8A, 9A) for returning the cooled fluid into the container.

15. Apparatus according to claim 14 for filling a container (3) carried by a movable vehicle (1) characterized in that the first (9A) and second (9B) connectors are detachable.

16. Apparatus according to claim 15 characterized by flexible lines (8A, 8B) connecting the compressor (11) to the detachable inlet connection (9A) and connecting the detachable outlet connection (9B) to the cooling arrangement (15).

17. Apparatus according to claim 16 characterized by means (2) for weighing the vehicle (1) as the container (3) is filled and for terminating the filling operation when a preset weight or change in weight is reached.

18. Apparatus according to claim 17 characterized by means for weighing an assembly (10, 14), the latter comprising a source (10) of the gas to be pressurized and the cooling arrangement (14), and for terminating the filling operation when the change in weight indicates that a preset amount of fluid has been dispensed into the container (3).

19. Apparatus according to any one of claims 14 to 18 for filling a container (3) forming a reservoir for propellant located in a space vehicle (1) and characterized by a mechanism for moving the apparatus to and from a position from where the vehicle (1) is to be prepared prior to launch.

20. Apparatus according to any one of claims 14 to 19, characterized in that an output of the cooling arrangement (15) is connected to a vertically extending pipe or column (15C) in which, in use, the cooled fluid, of increased density, accumulates, providing thermosyphonic pressure serving to circulate the fluid to and from the cooling arrangement (15).

21. Apparatus according to claim 20 characterized by a heater (17A) for heating the fluid adjacent to the bottom of the pipe or column (15C).

22. A method of depressurizing fluid in a container (3) characterized in that the minimum temperature

caused by the depressurization is controlled by heating some fluid released from the container and re-introducing the heated fluid into the container.

- 23.** Apparatus for depressurizing fluid in a container (3) 5
characterized by means (16B, 15, 15C) for with-
drawing a proportion of fluid released from the con-
tainer, a heater (17A) for heating it, and means
(16A, 8A, 9A, 6A) for re-introducing the heated fluid
into the container. 10
- 24.** A method of controlling the temperature of fluid in
an insulated tank characterized in that a thermosy-
phonic effect is used to circulate the fluid and in that
the temperature is controlled at an outlet of the ther-
mosyphon. 15

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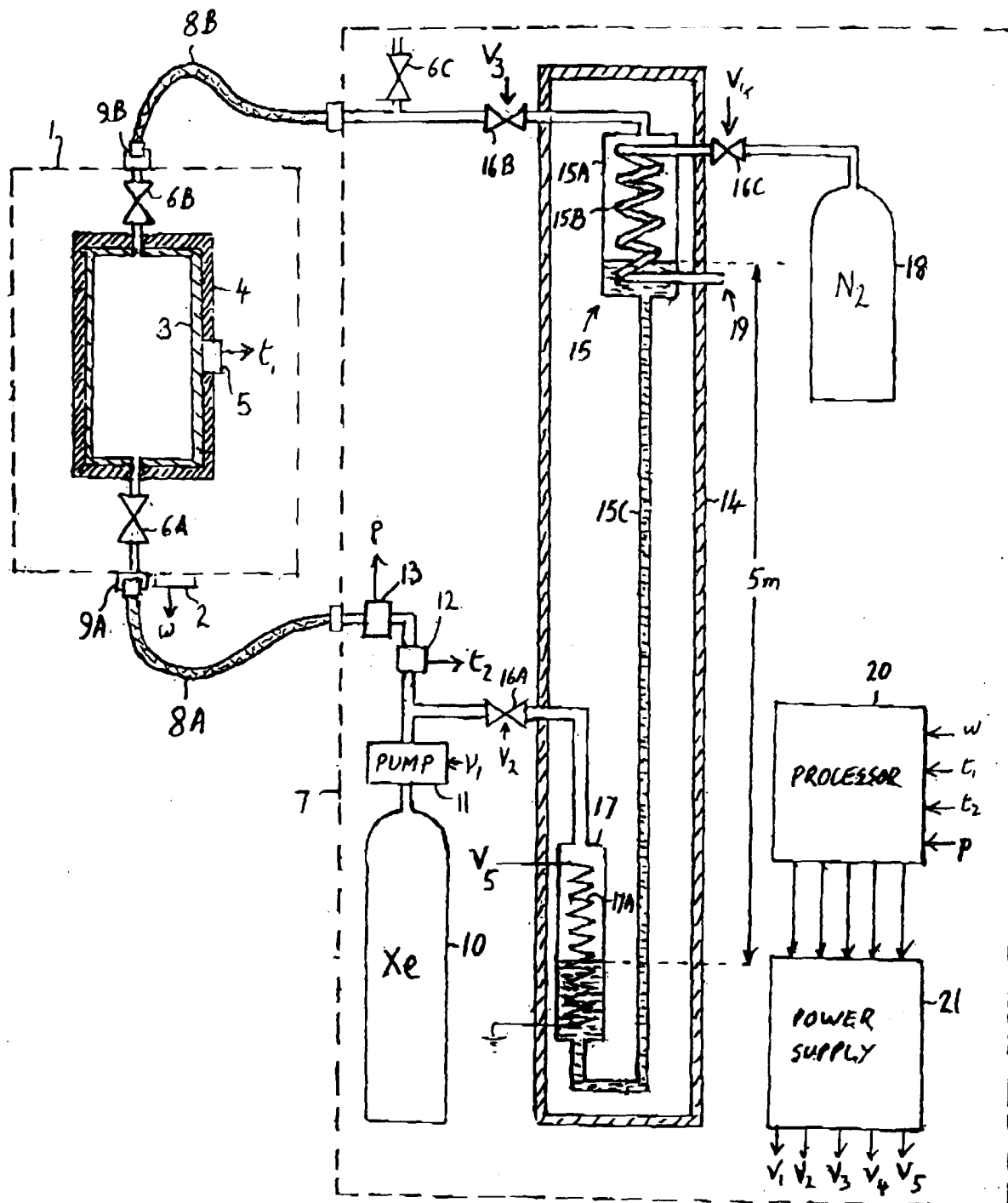
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European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 99 30 8100

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The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 27 December 1999	Examiner Meertens, J
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 (P4/C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

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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
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