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(71) Applicant: **LINDE AKTIENGESSELLSCHAFT**
[DE/DE]; Klosterhofstrasse 1, 80331 München (DE).

(72) Inventors: **ADLER, Robert**; Lorenz-Steiner-Gasse 34,
2201 Gerasdorf (AT). **STEPHAN, Markus**; Raitlstrasse
59, 2392 Dornbach (AT). **MC KEOWN, Kyle**; 801 Fill-
more Street, Apt. 15, San Francisco, CA 94117 (US).

PICKLES, Jeffrey; 891 Lois Avenue, Sunnyvale, CA
94087 (US).

(74) Agent: **GELLNER, Bernd**; LINDE AG, Technology &
Innovation Corporate Intellectual Property, Dr.-Carl-von-
Linde-Str. 6-14, 82049 Pullach (DE).

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(54) Title: UNDERGROUND LIQUEFIED CRYOGENIC FLUID STORAGE, FILLING AND PRESSURE CONTROL

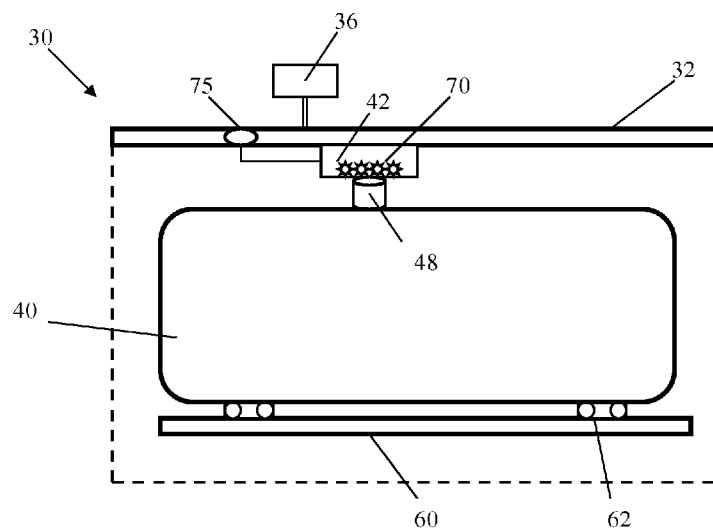


FIG. 2

(57) Abstract: An underground storage tank for liquid hydrogen that improves safety, requires less complex components and can be installed in a smaller footprint than known tanks. The tank eliminates the need for explosion control systems, deflagration vents, life support systems and complex ventilation systems. The tank is buried to reduce the risk of containment loss and explosion and includes a neck portion that extends to a gas cabinet with a manifold for the pipes and process streams. A control system is included to provide automation and remote pressure control of the liquid hydrogen in the tank. The design provides intrinsic safety because the liquid level of the hydrogen is below grade and below the normal leak points.

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UNDERGROUND LIQUEFIED CRYOGENIC FLUID STORAGE, FILLING AND PRESSURE CONTROL

FIELD OF THE INVENTION

(001) The invention relates to a new design for an underground (below-grade) liquid hydrogen tank.

BACKGROUND OF THE INVENTION

(002) Hydrogen tanks for storage of liquid hydrogen to be used for fuel are known. These tanks are normally vacuum jacketed tanks as needed to enable storage of the cryogenic liquid hydrogen. In many cases these tanks are established above ground and are subject to rigid safety requirements. In some instances, the vacuum jacketed tank may be installed underground. For example, US published patent application 2006/0162811 describes such an underground storage installation. However, the known underground storage installations for liquid hydrogen include relatively complex construction designs to prevent leakage and increase safety. Such designs include vacuum-jacketed valves, pipes and other components; vent systems; explosion control systems, life support systems, etc. Many of the prior art designs are built as vaults, e.g. confined spaces that are enterable and may be manned. These design parameters make such installations costly and complex to build and operate.

(003) There is a need in the art for improvements to the design of underground installations for the storage of liquid hydrogen.

SUMMARY OF THE PRESENT INVENTION

(004) The invention relates to a liquid gas storage facility and a method for operating such a liquid gas storage facility according to the independent claims. The dependent claims relate to preferred embodiments of the invention.

(005) The invention provides an underground storage tank for liquid gas, in particular for liquid hydrogen, that improves safety, requires less complex components and can be installed in a smaller footprint than known tanks.

DETAILED DESCRIPTION OF THE INVENTION

(006) The invention relates to the design for an underground/below grade liquid gas storage tank that does not require occupancy, and is not enterable. The design according to the invention improves safety by minimizing or eliminating the need for explosion control systems, deflagration vents, life support systems and complex room or building ventilation systems, all of which are necessary to manage the risks in vaulted underground liquid hydrogen storage facilities.

(007) The design according to the invention reduces installation and operating costs and requires a small installation footprint than known installations for underground liquid hydrogen storage. The design of the invention promotes the hydrogen economy because such can be used in large scale hydrogen fueling stations at reduced fuel costs.

(008) One advantage of the invention is that gas cabinet for the installation also has a much smaller footprint than those needed for prior art structures. The vault systems known in the prior art are large and require numerous auxiliary components and systems that also take up significant space. The design of the invention however eliminates the need for many of these auxiliary systems and therefore needs less equipment and control components. This is beneficial as the control cabinet, i.e. the gas cabinet described in

more detail below, can also be much smaller and less complex in design, thereby reducing costs related to equipment as well as footprint.

(009) The design according to the invention reduces the risk of containment and explosions that are associated with the storage of liquid hydrogen in public areas (e.g. fueling stations). This is accomplished by burying the storage tank. This is particularly effective at reducing the risk of containment loss and explosion that may be caused by vehicle impacts, fires and terrorist activity. The design of the invention is beneficial because by burying the tank, the tank is removed from exposure to vehicles, projectiles, fires, etc. which could jeopardize the mechanical integrity of the inner and outer vessels making up the tank.

(010) In addition, the design of the invention reduces the risk of hydrogen leaks and fires to the surrounding area by encapsulating the leak points and venting to a safe location. Intrinsic safety is provided by the design of the invention by locating the liquid level below grade and below the probable leak points, e.g. valves, fittings, and pipework.

(011) According to the invention all valves are located above the maximum fill level of the tank. The maximum fill level is such that the tank volume below the maximum fill level is preferably more than 75% of the total tank volume, more than 80% of the total tank volume or more than 90% of the total tank volume.

(012) In a preferred embodiment the tank includes a neck portion at the top of the tank wherein the neck portion carries the hydrogen piping in a vacuum jacket. More preferably, the neck portion leads to a gas cabinet. The gas cabinet preferably contains the necessary valves, fittings and instrumentation for filling the tank.

(013) Further, the gas cabinet may be constructed as a pressure vessel. In that case it is preferred that the gas cabinet contains an inert atmosphere, in particular a helium atmosphere.

(014) In another embodiment, the tank comprises a fill line with a first valve wherein the fill line is connected to the tank above the maximum fill level, and that the tank comprises a liquid draw line with a second valve wherein the liquid draw line opens into the tank volume below the maximum fill level, wherein the fill line is connected to the liquid draw line downstream of the second valve. The liquid draw line may further comprise means to determine the pressure downstream of the second valve. In addition, the liquid draw line may be connected to a compressor or a pump. These features allow an improved way of pressure building of the tank as described in more detail below.

(015) The invention also relates to a method of operating a liquid gas storage facility as described above, in particular for pressure building of the tank. After dispensing of the liquid gas from the tank the second valve is closed, the pressure downstream of the second valve is determined and compared to a setpoint pressure, and if the pressure downstream of the second valve is greater than the setpoint pressure the first valve is opened. Thereby, liquid gas in the pipework between the first valve and the compressor is vaporized and returned to the head space of the tank. This eliminates the need for a pressure build-up coil or another pressure build-up system.

(016) The advantages of the invention are accomplished by providing a liquid hydrogen storage tank that minimizes the number of nozzles and welds. The tank includes a neck portion at the top of the tank where the outer vessel extends to the ground surface, the neck portion carrying the hydrogen piping in a vacuum jacket. The neck portion extends to a gas cabinet or enclosure with a manifold for the pipes and process streams wherein the cabinet is accessible for maintenance. The gas cabinet is designed to hold all of the

necessary valves, fittings, instrumentation and piping needed for tank filling and dispensing to the fueling station, including compressors. The gas cabinet is constructed as a pressure vessel and maintains an inert atmosphere within the cabinet. The inert atmosphere is desirably a helium atmosphere, which helps to prevent condensation of other inert gases in the presence of liquid hydrogen.

(017) The design according to the invention also includes a control system that allows for performance automation and remote pressure control of the liquid hydrogen in the tank during the filling process. The control system includes detection means to sense unsafe conditions and automatically respond as necessary, e.g. leak mitigation, automatic shut-down, pressure building or venting. The control system of the invention allows a tanker truck driver to perform the fill of the underground tank. The automation and control are necessary because the driver will not have access to valves on the buried tank. The control system is beneficial because it increases the efficiency of the filling procedure by having automated controls that can optimize the filling parameters. This leads to less venting of hydrogen than currently practicable by the manual filling procedures used for prior art systems. In general, the measurements needed for precise control of the filling are not available to the driver, which often leads to over venting during the filling process. Further, the control system of the invention improves safety to the driver because of the automation of leak detection and shutoff, that previously required human intervention.

(018) The installation according to the invention is designed to meet or exceed codes and standards, particularly those in the United States and Canada related to the installation of underground liquid hydrogen tanks. The invention is particularly focused on installations that are to be placed in the forecourt of the fueling station where public safety, footprint, cost and delivery are of paramount importance.

(019) The design according to the invention allows for heat integration of cryogenic fluids to aid in high pressure hydrogen fueling. For example, thermal/metal storage heat exchangers and heat exchangers that make use of cryogenic hydrogen vents associated with cryopumps and cryocompression can be incorporated into the system and used for pre-cooling the hydrogen being dispensed to vehicles.

(020) An important feature of the invention is the ability to handle pressure building in the tank. A control scheme that increases tank pressure following a fueling or compression event is followed, the scheme allowing liquid hydrogen in the pipework leading to the compressor to be vaporized and expanded back into the liquid hydrogen tank vapor space. This is especially important at a fueling station where compressors are cycled on and off as part of normal operation. By using the scheme, the need for pressure building coils or heat exchangers is eliminated. This provides for easier installation as the incorporation of such coils or heat exchangers is difficult in an underground system, since the liquid level is below grade. In addition, this scheme provides greater efficiency to the system as it improves on the current standard of using ambient air/heat to vaporize a small amount of liquid for return to the tank vapor space. The known pressure build systems also have a tendency to cause hydrogen releases when they fail open or leak to the atmosphere. These tendencies are avoided by the system of the invention.

(021) For many fuel tanks, the customer valve (either liquid draw or vapor draw) is in the open position at all times (absent an e-stop). However, for hydrogen fueling stations, this practice has been determined to be unsafe as a small leak from downstream equipment could accumulate in housings or compressor enclosures. Therefore, the valve in hydrogen fueling stations is closed after the compressor turns off. This can leave liquid trapped in the line that must be vaporized and vented as noted above. This leads to a loss of efficiency. This loss is avoided by the invention. The pressure build feature of the invention provides these benefits but is also an essential feature for proper functioning of

the system according to the invention. Without a way to build pressure, the tank would eventually lack enough pressure to dispense the hydrogen and would cease functioning. With the tank underground, the traditional pressure build coils are not practical. Therefore, a different pressure build scheme is needed and will be described in more detail below.

(022) As noted, the design of the invention provides some intrinsic safety because the liquid level of the hydrogen is below grade and below the normal leak points, e.g. valves, pipework, etc. In the known hydrogen storage tanks, leaks or loss of containment at the tank pipework will persist until the tank is empty or the leak stops because of liquid head or pressure. Venting the pressure of the tank can help, but the liquid head will continue to drive flow. According to the invention, the tank is below grade and any leak at the valves or pipework can be stopped quickly by venting-off pressure from the vapor space of the tank.

(023) The liquid hydrogen tank and installation design of the invention will be described in more detail with reference to the attached drawing figures.

(024) Figure 1 is a top plan view of a liquid hydrogen storage and dispensing system according to the invention.

(025) Figure 2 is a plan view of the buried tank used in the system according to the invention.

(026) Figure 3 is a schematic view of the buried tank according to the invention illustrating the pressure build process.

(027) Figure 1 is a top plan view of a liquid hydrogen storage and dispensing installation according to the invention. In Figure 1, the installation 100 includes a store or office 10, a fueling or dispensing pad 20 having multiple dispensers 25 and hazard zone 30 where the buried tank 40 is located. The hazard zone 30 is constructed to meet appropriate standards, such as those for class 1, division 2 hazard zones and group 1 exposures (NFPA Standard 55). For example, the hazard zone 30 may be of generally circular construction having a 25 diameter. The hazard zone 30 includes a concrete pad 32 that includes a spill pad, a bollard area 34 to surround an off-loading control panel 36. The hazard zone 30 surrounds the buried tank 40 that connects with a gas cabinet 42 which in turn connects to hydrogen equipment and vent 44 by means of a trench 46. Also shown in Figure 1 is a fueling tanker truck 50 that serves to fill the buried tank 40 through a fill connection 55 and can be controlled by the control panel 36.

(028) Portions of the hazard zone 30 will be described in more with reference to Figure 2 which shows a plan view of the installation according to the invention. In Figure 2, the buried tank 40 is shown in its installed position within the hazard zone 30. The tank 40 is connected to a concrete foundation 60 via multiple anchor bolts 62. The tank 40 includes a neck portion 48 that leads to the gas cabinet 42 that in turn houses a manifold 70 for the valves, pipework etc of the system. The concrete pad 32 is in place at the ground surface and may comprise a six inch thick concrete slab with about a foot of dirt between the lower surface of the concrete pad 32 and the upper surface of the buried tank 40. The concrete pad 32 also extends approximately a foot between the outer dimensions of the buried tank 40. The tank 40 may be a standard vacuum jacketed liquid hydrogen tank, such as an ASME Section VIII tank. The tank 40 is designed to have about a six inch vapor space in the upper portion of the tank 40. The gas cabinet 42 is connected to a bayonet type fill connection 75 as well as to the control panel 36 to facilitate filling of buried tank 40.

(029) Figure 3 is a schematic view of the buried tank according to the invention illustrating the pressure build process. As shown in Figure 3, the tank 40 has a liquid level 200. A liquid draw line 210 communicates with the liquid in the tank for purposes of dispensing the liquid through a valve 220. A fill line 230 communicates with the interior of the tank 40 through nozzles 235 and a valve 240. A first pressure sensor 240 communicates with the fill line 230 and a second pressure sensor 260 communicates with a connection between the draw line 210 and the fill line 230.

The pressure build scheme will be explained with reference to Figure 3. Initially, the control system determines whether the compressor is on. If not, then the pressure from pressure sensor 360 is compared to a predetermined setpoint pressure. If the sensed pressure is greater than the setpoint pressure, then valve 240 is opened for five (5) seconds and then closed.

(030) If the compressor is on, then valve 220 is open to allow liquid draw from the tank 40. When dispensing is complete and the compressor is turned off, valve 220 is closed. Valve 240 is opened and a timer is started. This allows for the pressure build to occur. When the timer expires after a predetermined time, valve 240 is closed. At this point, the appropriate pressure has been established in the tank 40 for further dispensing.

(031) While the invention has been described above with respect to liquid hydrogen storage and fueling, the invention may also be used for other cryogenic storage vessels, such as for LNG (liquid natural gas), atmospheric gases, etc. The invention is particularly useful for the storage and dispensing of combustible gases, like hydrogen or LNG, where concerns of fire and explosion are higher and drive high costs based on complex safety systems and separation distances from near by populated area required by local codes and regulations.

(032) It is anticipated that other embodiments and variations of the present invention will become readily apparent to the skilled artisan in the light of the foregoing description, and it is intended that such embodiments and variations likewise be included within the scope of the invention as set out in the appended claims.

What is claimed:

1. A liquid gas storage facility comprising an underground liquid gas tank with a maximum fill level wherein pipes, valves and instrumentation are connected to the tank, characterized in that all valves are located above the maximum fill level.
2. A liquid gas storage facility according to claim 1 characterized in that the maximum fill level is such that the tank volume below the maximum fill level is more than 75% of the total tank volume, more than 80% of the total tank volume or more than 90% of the total tank volume.
3. A liquid gas storage facility according to any of the preceding claims, characterized in that the tank includes a neck portion at the top of the tank wherein the neck portion carries the hydrogen piping in a vacuum jacket.
4. A liquid gas storage facility according to claim 3 characterized in that the neck portion leads to a gas cabinet.
5. A liquid gas storage facility according to claim 4 characterized in that the gas cabinet contains the necessary valves, fittings and instrumentation for filling the tank.
6. A liquid gas storage facility according to claim 4 or 5, characterized in that the gas cabinet is constructed as a pressure vessel.
7. A liquid gas storage facility according to any of claims 4 to 6, characterized in that the gas cabinet contains an inert atmosphere, in particular a helium atmosphere.

8. A liquid gas storage facility according to any of the preceding claims, characterized in that the tank comprises a fill line with a first valve wherein the fill line is connected to the tank above the maximum fill level, and that the tank comprises a liquid draw line with a second valve wherein the liquid draw line opens into the tank volume below the maximum fill level, wherein the fill line is connected to the liquid draw line downstream of the second valve.

9. A liquid gas storage facility according to claim 8, characterized in that the liquid draw line comprises means to determine the pressure downstream of the second valve.

10. A liquid gas storage facility according to claim 8 or 9, characterized in that the liquid draw line is connected to a compressor or a pump.

11. A liquid gas storage facility according to any of claims 8 to 10, characterized in that the first valve is in communication with a timer.

12. A liquid gas storage facility according to any of the preceding claims, characterized in that the liquid gas tank is designed for the storage of a liquid cryogenic gas, in particular for storage of liquid nitrogen, liquid oxygen or liquid natural gas, and in particular for storage of liquid hydrogen.

13. A method of operating a liquid gas storage facility according to any of the preceding claims, characterized in that after dispensing of the liquid gas from the tank the second valve is closed, the pressure downstream of the second valve is determined and compared to a setpoint pressure, and if the pressure downstream of the second valve is greater than the setpoint pressure the first valve is opened.

14. A method of operating a liquid gas storage facility according to claim 13, characterized in that the first valve is opened for a predetermined time and that the first valve is closed after expiry of the predetermined time.

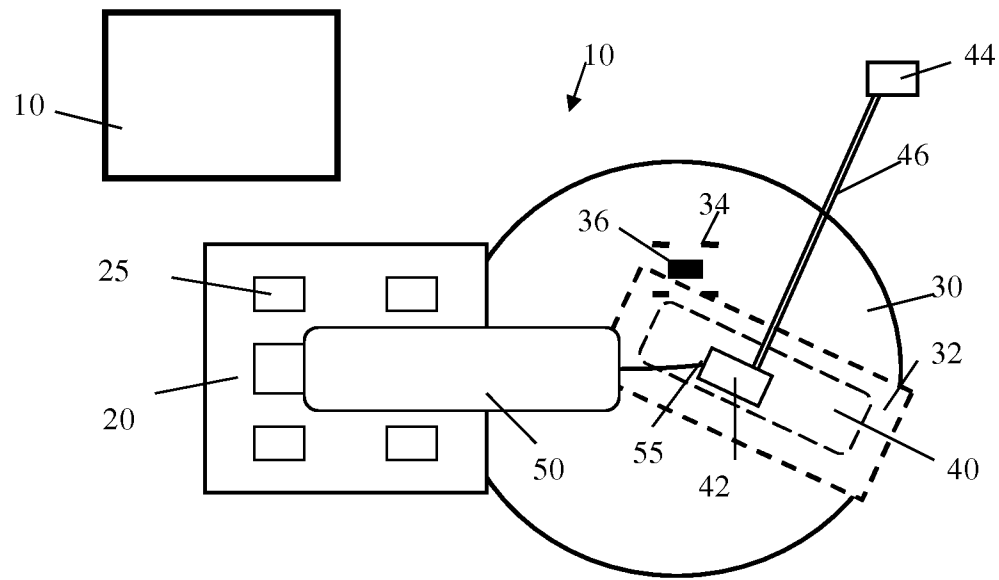


FIG. 1

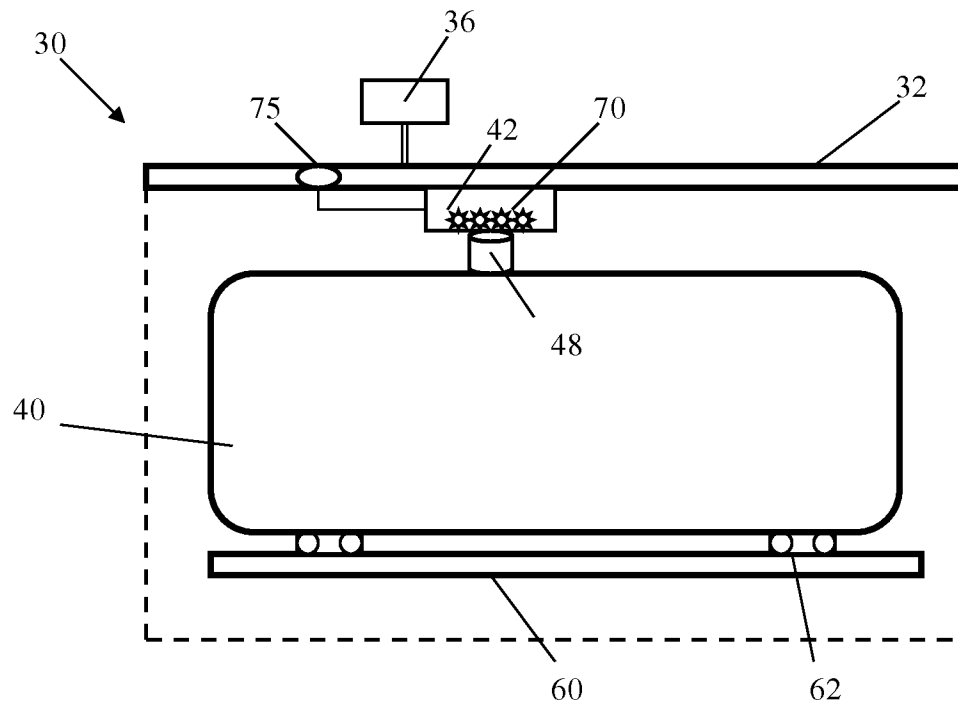


FIG. 2

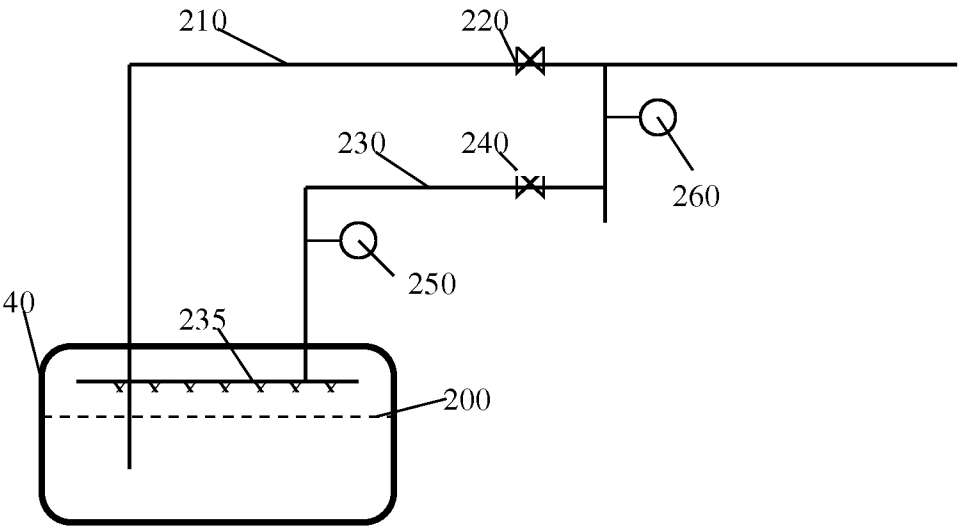


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/025232

A. CLASSIFICATION OF SUBJECT MATTER
INV. B67D7/00 F17C7/00
ADD.

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)
F17C B67D

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2004/083713 A2 (PRAXAIR TECHNOLOGY INC [US]; WHITE NORMAN HENRY [US]) 30 September 2004 (2004-09-30)	1-3,8-14
Y	figures 1,2 paragraphs [0023] - [0039] -----	4-7
Y	WO 94/13576 A1 (FIECH MANFRED M [US]) 23 June 1994 (1994-06-23)	4-7
A	figures 1,2 page 7, lines 12-21 page 10, lines 24-27 page 3, line 20 - page 4, line 6 page 7, line 23 - page 8, line 1 page 9, line 7 - page 9, line 11 -----	1-3,8-14



Further documents are listed in the continuation of Box C.



See patent family annex.

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European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Sisinni, Giovanni

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2004083713 A2	30-09-2004	US 2004182470 A1 WO 2004083713 A2	23-09-2004 30-09-2004
WO 9413576 A1	23-06-1994	AU 5738294 A CA 2151374 A1 EP 0672018 A1 US 5390713 A US 5586586 A WO 9413576 A1	04-07-1994 23-06-1994 20-09-1995 21-02-1995 24-12-1996 23-06-1994