(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 October 2012 (26.10.2012)

WIPO | PCT

(10) International Publication Number
WO 2012/143740 A2

(51) International Patent Classification: Not classified

(21) International Application Number: PCT/GB2012/050895

(22) International Filing Date: 23 April 2012 (23.04.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1106812.9 21 April 2011 (21.04.2011) GB
1117023.0 4 October 2011 (04.10.2011) GB

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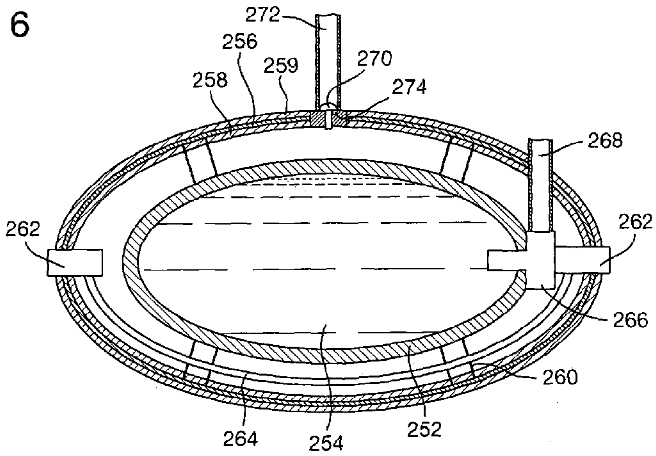
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) **Title**: GAS STORAGE

Fig. 6



(57) **Abstract**: A gas storage vessel comprises an internal tank that is at least partially surrounded by an external tank having a higher fire resistance than the internal tank, e.g. formed of incombustible material that excludes permeation, and a pressure relief device. The internal tank is designed to store gas at a higher pressure than the external tank, and is made of comparatively lightweight materials through which hydrogen can permeate with comparatively low fire resistance. The external tank has means to control leaks from the internal tank. The PRD may have a variable aperture, which is small in the beginning of the release and increases to the end of the blowdown, and which prevents high flame length and generation of destructive overpressure within an enclosure, such as a garage, at the start of the release. The gas storage vessel can provide safe onboard storage of compressed flammable gases, with enhanced fire resistance and reduced flame length from the pressure relief device, especially for hydrogen-powered vehicles.

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109167/02

Gas Storage

The present invention relates to vessels for gas storage and pressure relief devices for gas storage vessels , in particular for flammable gas storage, for example hydrogen storage. The present invention may find particular application to the on-board storage of hydrogen with enhanced fire resistance and reduced flame length.

Flammable gases, such as hydrogen, are typically stored under high pressure in metal or composite material storage tanks or cylinders. Type 1 or Type 2 tanks are made from metal (steel/aluminium) but have a maximum pressure of 200-300 bar. They are considered to be too heavy for automotive applications requiring storage pressure from 350 to 700 bar to provide a driving range comparable with gasoline cars. Onboard storage tanks for hydrogen powered vehicles typically operate at pressures up to 700 bar and are currently accepted, due to their comparatively light weight, to be Type 4 tanks made from fibre-reinforced composite materials with polymer liner or Type 3 with aluminium liner. In the event of a collision and/or in a fire, the hydrogen storage tank represents a considerable hazard due to risk of explosion or catastrophic vessel failure at high temperature followed by a severe blast wave. This is because composite materials typically can not stand fire for very long before undergoing catastrophic failure (currently from 1 to 6.5 minutes). It is therefore necessary to provide such tanks with a pressure relief device (PRD) to release the gas from the storage tank in a safe manner before catastrophic vessel rupture can occur.

To release (blowdown) hydrogen in such a short time (e.g. a few minutes), current PRDs have release orifices of about 5 mm. Unfortunately, such a PRD will release about 4.4 m^3 of hydrogen per second (at 350 bar) that would destroy a closed typical garage of about 40 m^3 free space in about 1 second. As a result there will not even be a chance for evacuation in case of accident. The only engineering resolution of this issue is a decrease of release flow rate (to save a garage-like structure and give people chance to escape the scene of accident). This will increase the blowdown time and thus the fire resistance of a storage vessel must be increased from the current few minutes to at least tens of minutes.

Metal storage tanks have relatively high fire resistance, especially when additionally protected e.g. by intumescent paint etc., but due to their high thermal conductivity the contained gas will quickly heat up and the PRD must act before the pressure increases to a level where there is a risk of metal tank rupture due to overpressure. Known PRDs typically include a fusible (i.e. rupturable by fire) member upstream of an outlet vent, whereby the fusible member melts when the tank is exposed to high temperatures so that the gas pressure can operate to open the outlet vent above a predetermined temperature. Alternatively, or additionally, a burst disk or frangible member may be provided upstream of the outlet vent whereby the burst disk or frangible member fails above a predetermined pressure.

Current high pressure storage vessels for compressed fuel (e.g. onboard storage of hydrogen) are made of comparatively light composite materials containing carbon fibre and resin which are not resistant to fire. Due to “breathing” (in other words, expansion and contraction) of such tanks with internal pressure change during its use, it is difficult to protect the tank by e.g. intumescent paint that will crack with time and lose its performance if fire were to take place. As a result, the fire resistance of such tanks is unacceptably short and typically of the order of 1-6.5 minutes depending on tank size, internal pressure, fire test conditions, etc. For carbon fibre reinforced (Type 4) vessels, the internal pressure does not increase quickly in fire like in the case of metal vessels due to the low thermal conductivity of the carbon fibre material, and in fact the tank is usually destroyed by fire (due to thermal degradation, low melting temperature of plastics and resins, etc.) before the pressure grows to a dangerous level. Once the tank burns through, it could catastrophically fail or huge jet flames and fireballs could be fired through the hole(s) that are formed.

To prevent catastrophic failure of a storage vessel before the fuel is released, such vessels are designed currently to use pressure relief devices with high mass flow rates (i.e. large venting areas). However, at a typical storage pressure of 700 bar a PRD with a large outlet diameter of about 5 mm can result in a jet flame length of 10-15 metres. Moreover, a high mass flow release e.g. of hydrogen can destroy a civil structure such as a typical garage in a matter of 1-2 seconds without leaving any chance for the evacuation of people. Research has demonstrated that even the release through a 5 mm orifice from a 350 bar storage tank provides a volume flow rate 4.4 m^3/s. In a garage of 44 m^3 it will lead to a pressure increase from atmospheric pressure by 10% (or 10 kPa) in 1 second. Pressure of 10 kPa is a limit that civil structures could withstand without being destroyed.

The flame length of a flammable gas jet in air depends on the mass flow rate (storage pressure or density at the leak exit) and the size of aperture of the PRD as has been shown by research at the University of Ulster. During initiation of a PRD having a fixed pressure release area, the flame length is highest at the beginning due to highest pressure and then decreases with time as the pressure in the storage tank reduces.

US 2007/0261734 discloses a safety valve of a high pressure storage, in particular a hydrogen storage tank. In this safety valve the cross-sectional flow area in the pressure relief conduit tapers in the direction of flow in the manner of a cone and a spring-mounted valve plate moves according to the upstream pressure to adjust the cross-sectional flow area. As a result, the gas may be released at a constant and defined mass flow rate. Once an upstream fusible member melts in the event of a fire, the cross-sectional flow area is immediately open so that gas can be released from the compressed gas storage tank to the atmosphere via the relief conduit. A problem with the safety valve disclosed in US 2007/0261734 is that the relief conduit always provides a minimum cross-section of flow area so that gas will be released even in the event of malfunction of the fusible member. Another problem with US 2007/0261734 is that, at the initial moment of safety valve operation, the created flammable mixture cloud could be very large due to the maximum cross-section of flow area at initial position. In case of ignition the cloud could deflagrate or even detonate thus killing and/or injuring passenger(s) and people in the vicinity e.g. first responders to an accident involving a hydrogen-powered car.

According to a first aspect of the present invention there is provided a pressure relief device (PRD) for venting gas from a storage vessel, comprising gas discharge means actuable by gas pressure to move from a closed position to a first open position having a discharge area A_1 and biasing means arrange to move the discharge means against the gas pressure to a second open position having a discharge area A_2 greater than A_1.

Advantages of the pressure relief device is that the discharge means is not automatically open and must itself be triggered in response to a minimum gas pressure so as to move out of its closed position, and that the creation of a large flammable cloud during initiation of the PRD is mitigated or even fully excluded. An upstream trigger member may not necessarily be provided. Rather, the PRD can itself respond to elevated storage pressures in the event of a fire, especially when operating in conjunction with a metal storage tank. This can be beneficial as a potential problem with prior art PRDs is that the fusible element or other temperature responsive member typically used to trigger the opening of the PRD at a predetermined temperature may not be directly exposed to the fire, for example where the fire impinges on a hydrogen storage tank at a location remote from the trigger. Even where the PRD is used in conjunction with a temperature sensor for Type 4 vessels made of carbon fibre, resin and plastic liner, the default closed position of the discharge means can provide a more gradual release of gas as it moves into an open position. The release rate as well depends on pressure in the tank at the moment of initiation of the PRD.

In the case of a constant aperture PRD an unacceptably high mass flow rate is released in the beginning of the blowdown when the storage pressure is highest. This can destroy a structure such as a garage or give rise to unacceptably long flame length as in current engineering solutions.

The problems with closest known technologies include the fact that there is too long a flame in the beginning of release as the aperture of the PRD is constant during the blowdown. Furthermore, there is a problem with long blowdown time when the storage pressure at the moment of accidental release is low compared to the maximum storage pressure. This increases the risk of catastrophic failure of the storage tank in a fire.

These problems are preferably solved through use of a PRD with a variable aperture, which is small in the beginning of the release and increases to the end of the blowdown, and which prevents high flame length and large fireballs at the start of the release.

Preferred embodiments of the present invention also seek to reduce a blowdown of the storage vessel time without increasing the maximum flame length. This is achieved by the discharge means moving to change the aperture size during the blowdown from a small one to a larger one with decreasing pressure. This is done based on the knowledge that the jet flame length reduces with the decrease of pressure and increases with the increase of the aperture size. The increase of aperture also increases the mass flow rate for the same pressure level.

A problem which is addressed by such a preferred embodiment is a reduction of the blowdown time of the fuel from a high pressure storage vessel without increasing the flame length from the PRD. This is done through using a PRD having variable aperture that prevents high flame length at the moment of PRD initiation. At an initial high pressure the discharge means provides a smaller discharge area A_1. As the pressure drops, the biasing means is able to move the discharge means into a position providing a larger discharge area A_2.

Preferably the discharge means moves between different open positions in response to gas pressure such that the discharge area increases as the gas pressure decreases and vice-versa. In other words, there is preferably two-way movement of the discharge means. The device is therefore able to actively and dynamically respond to changes in the storage pressure to ensure that the mass flow rate is maximised while also limiting the jet flame length. Once the discharge means has been moved out of its closed position in response to a minimum gas pressure, the effective open area of the discharge means is dependent on the current gas pressure, with open positions having larger discharge areas being accessed with reduced pressure.

The PRD according to preferred embodiments may be used in process safety industries, vehicles with alternative fuels such as hydrogen, LPG and CNG, and pipelines etc. The preferred PRD is also particularly suitable for use with hydrogen-powered vehicles having carbon fibre fuel tanks.

In at least one set of embodiments, the device may further comprise at least one heat sensitive trigger means arranged to isolate the discharge means from gas pressure in the vessel. Once the trigger means is actuated the discharge means becomes sensitive to gas pressure and can be moved out of its closed position in response to a gas pressure above a predetermined threshold. The heat sensitive trigger means may comprise a fusible or combustible member, glass bulb or any other suitable heat sensitive trigger means.

A benefit of providing a trigger means upstream of the pressure relief device is that the discharge means can be prevented from reacting to gas pressure leaks and is only actuated in the event of an emergency such as a fire.

A heat or temperature sensitive trigger means can be particularly useful when the PRD is used to release pressurised gas from a storage vessel made of fibre-reinforced polymer, which is likely to fail due to burning through rather than due to a pressure build-up resulting in explosion. Thus when viewed from a second aspect the present invention provides a pressurised gas storage system comprising a storage vessel formed of fibre-reinforced polymer, a temperature or heat sensitive trigger means, and a pressure relief device (PRD) arranged to be exposed to gas pressure from the storage vessel upon actuation of the temperature or heat sensitive trigger means. Preferably the PRD has a variable discharge area, as is described above, preferably comprising gas discharge means actuable by gas pressure to move from a closed position to a first open position having a discharge area A_1 and biasing means arrange to move the discharge means against the gas pressure to a second open position having a discharge area A_2 greater than A_1. Any of the preferred features described above with respect to the first aspect of the invention may equally be provided in conjunction with this second aspect of the invention.

There will now be described some general features that apply to both aspect of the invention outlined above.

Movement of the discharge means from its closed position (zero discharge area) to the first, second or optionally further open positions (having a non-zero discharge area A_1, A_2 or A_x) may involve the movement of one or more members. In one example, the discharge means may comprise one of more vent openings with a valve member moving in response to gas pressure to open or close off the vent openings. In another example, a valve member comprising one or more vent openings may move in response to gas pressure so as to adjust the overall discharge area provided. In yet another example, relative movement between two or more valve members may define the effective discharge area. It will be understood that the discharge area is the overall effective area of the discharge means, which may be provided by multiple vents openings.

Movement of the discharge means between the first, second and optionally further open positions may be continuous or stepwise. The discharge means may have multiple open positions providing a range of different discharge areas.

Movement of the discharge means from its closed position in response to gas pressure may be achieved in various ways, e.g. movement may be actuated by a pressure sensor such as a pressure sensitive transducer e.g. a piezoelectric transducer. However, in a preferred set of embodiments the discharge means is held in its closed position by a mechanical biasing means such as a tension or compression spring, or a resilient diaphragm member. A spring biasing means may be in the form of a coil spring, leaf spring or resilient member and may be made of metal, plastic or elastomeric material. A predetermined gas pressure may be required to overcome the biasing means.

In a preferred set of embodiments the discharge means comprises a piston-like dispersing member provided with at least one vent opening formed therein. The dispersing member may be slidably mounted within a body of the device to be movable between a retracted position, wherein at least one vent opening is obscured by a portion of the device body, and an extended position, wherein the dispersing member projects from the body to expose its vent opening(s). Preferably the dispersing member comprises a substantially tubular body mounted within a cylindrical opening in the device body. Preferably the at least one vent opening extends through a side wall of the tubular body. Preferably the dispersing member is provided with a plurality of vent openings formed in the side wall of the tubular body. One or more of the vent openings may be angled to impart rotation to the tubular body during the escape of gas therefrom. An upper part of the tubular body may comprise a domed or conical head portion. At least a portion of the one or more vent openings may extend through the domed or conical shaped portion.

In one set of embodiments, the vent openings may take the form of axially and/or circumferentially extending slots. The individual discharge area of each slot may be relatively small (in order to increase diffusion of gas and reduce gas speed as it is expelled, enhancing dilution of the gas). However, the combined discharge area of the slots may be relatively large to ensure adequate flow rate to achieve the required blowdown time, especially once the pressure has reduced from initial levels.

The discharge means may comprise a blocking member e.g. located within a tubular body of the dispersing member, the blocking member being movable between a closed position obscuring the vent openings, and an open position that opens the vent openings. The blocking member may be adapted to move towards its open position under the action of high pressure gas within a gas storage vessel when the device is activated.

As is mentioned above, one or more vent openings in the discharge means may comprise one or more axially extending slots extending through a side wall of a tubular body in a dispersing member. As the discharge means moves from its first open position to its second or optionally further open positions having a larger discharge area, the effective discharge area of the axially extending vent openings may gradually increase as the piston moves relative to the tubular body. This increases the flow rate as the pressure drops and avoids excessive flame length upon initial activation of the device while ensuring a relatively high mass flow rate overall. The provision of multiple vent outlet enhances dilution of the escaping gas with air while maintaining sufficient flow rate to achieve rapid blowdown.

In one set of embodiments a valve means may be provided upstream of the discharge means, the valve means isolating the discharge means from high pressure gas from the vessel, the valve means being associated with a heat sensitive trigger means for allowing the communication of high pressure gas with the discharge means so that the discharge means can move out of its closed position in response to gas pressure. Preferably the valve means comprises a further rupturable or displaceable member adapted to be supported against the force applied thereagainst by the high pressure gas directly or indirectly by the heat sensitive trigger means. The heat sensitive trigger means may comprise a moveable support member displaceable between a first position, wherein the support member supports the further rupturable member, and a second position wherein the further rupturable member is unsupported and wherein gas can flow through the further rupturable member to act against the discharge means, the moveable support member being retained in its first position by means of at least one fusible or combustible member.

The present invention also extends to a gas storage vessel comprising a pressure release device provided according to any of the embodiments described above. Particularly where a high pressure compressed gas such as hydrogen is contained in the storage vessel, the pressure relief device is important for controlling the mass flow rate upon discharge. However, the flow rate provided by the PRD needs to be matched to the material of the storage vessel and its fire resistance so that the mass flow rate is fast enough to prevent catastrophic failure of the vessel. If the PRD does not release the compressed gas quickly enough in the event of a fire, the vessel may burn through or "melt" before the gas has been sufficiently discharged, particularly where the vessel is made from a composite material such as carbon fibre reinforced resin and polymer liner which all have a relatively low fire resistance.

As is discussed above, using a PRD to provide a high mass flow rate release from a high pressure vessel, such as a composite storage tank for hydrogen gas, may allow the tank to be vented before it is destroyed by fire but can result in problems outside the tank. In particular, when a hydrogen-powered vehicle in stored in a garage (or other confined structure) the vented gas may not be able to escape fast enough from the external structure, which usually can stand internal overpressure of the order of 10 kPa only, and the risk of accident escalation with explosion/destruction of the structure remains.

Preferably there is provided a gas storage system comprising a gas storage tank and a pressure relief device as described above and further comprising a low pressure external tank made of incombustible material. Preferably the external tank excludes permeation of hydrogen and has a fire resistance sufficient for safe (slow) blowdown of hydrogen within garage-like enclosures. The internal tank may be arranged at least partially inside the external tank.

Such a system addresses the problem that unacceptably high mass flow rates from conventional PRDs will lead to destruction of civil structures such as a typical garage in seconds, but this is currently substantiated by a need to release the contents of the high pressure vessel quickly before it would have a catastrophic failure in an external fire. This issue is solved by increasing the fire resistance of the gas storage system by using two different tanks. The external tank e.g. made of metal can be designed to contain low pressure gas so that the walls do not have to be made thick and heavy. However the material of the external tank can be chosen to have a higher fire resistance than that of the internal tank. The fire resistance of the external tank can be increased by using fire protection means, e.g. intumescent paint. The space between tanks can be filled by inert gas or a material releasing inert gas during thermal impact. The external tank advantageously provides combustion protection for the internal tank, which may be designed to contain high pressure gas and made from relatively light but combustible material such as carbon fibre reinforced polymer or resin/fibre reinforced resin and polymer liner. When high pressure gas is contained in a double layered tank with an increased fire resistance on the outside, the safe blowdown time can be extended and the PRD does not have be discharged with such a high mass flow rate, thereby avoiding dangerous flame lengths and the risk of high pressure gas being rapidly released into a confined space such as a garage at rates able to destroy the structure.

This is considered novel and inventive in its own right, and thus when viewed from a third aspect the present invention provides a gas storage vessel comprising a pressure relief device and an internal (preferably high pressure, e.g. lightweight) tank that is at least partially surrounded by an external (preferably lower pressure, e.g. lightweight) tank having a higher fire resistance than the internal tank. The lower pressure external tank is made of incombustible material that excludes permeation and is preferably covered by fire resistant materials from outside and inside. The space between the tanks may be at least partially filled by an inert gas such as nitrogen. Any of the preferred pressure relief devices, described above, may be used with such storage vessels for onboard storage of compressed fuels with increased fire resistance. Hydrogen-powered vehicles may particularly benefit from such a gas storage vessel.

This solution recognises that the use of metal-only vessels to withstand pressures up to 1,000 bar is impractical due to heavy weight and manufacturing difficulties. A dual tank design can increase the fire resistance of a compressed fuel storage system, as compared to composite materials typically used to store pressurised hydrogen e.g. at 700 bar, while also keeping the vessel comparatively lightweight. Such a design is therefore well-suited to the onboard storage of hydrogen (or other alternative fuels such as LPG and CNG) for next generation vehicles.

It is preferred that, in use, the internal tank stores a gas at a first pressure and the external tank stores a gas at a second, lower pressure. Preferably, there is a gas pressure difference between the internal and external tanks, in use, of at least 200, 300, 400, 500, 600, 700, 800, 900, 920, 940, 960, 980 or 990 bar. For example, the internal tank may withstand pressures up to 1000 bar while the external tank may be designed for a pressure of the order of 10 bar or 100 bar, or an overpressure of 10 bar, 1 bar, or even less.

Preferably the external tank is covered with fire resistant materials on its inside and/or outside surfaces. Any connecting means arranged between the internal and external tanks, e.g. for support purposes, are preferably designed to minimise heat transfer.

The choice of materials for the internal and external tanks is important. Preferably the internal tank is made of a lightweight composite material such as a fibre-reinforced polymer. Carbon or glass fibre reinforcement may be used. The internal tank may therefore be able to withstand the high pressure of hydrogen gas, e.g. pressures up to 700 bar. The applicant has recognised that under such high pressures, hydrogen (or other gas) may be able to permeate through composite polymer materials. However, such low level leakage may not be of concern as long as the external tank is made of an incombustible material such as metal that excludes permeation. The incombustible material of the external tank is preferably a metal or metallic alloy, such as aluminium or steel. In other words, the internal tank may be permeable to hydrogen gas while the external tank is impermeable to hydrogen gas.

The benefits of this design may be maximised by arranging the internal tank so as to be entirely contained within the external tank. The pressure relief device may communicate with the internal and/or external tank. However it is preferable that at least the internal (high pressure) tank is provided with a pressure relief device. The pressure relief device (PRD) preferably provides for the release of gas in the event of a fire (or other dangerous situation resulting in an increase of surrounding temperature and/or pressure in the vessel). The following features may be applicable to any gas storage vessel, whether it has a single or dual tank design.

A gas storage vessel may be provided with one or more pressure relief devices. Where each pressure relief device includes a trigger means it may be preferred to provide multiple pressure relief devices so that they can each react to a local fire as quickly as possible, especially when the storage vessel is relatively large. There is always the problem that a trigger means used to actuate the opening of a PRD at a predetermined temperature may not be directly exposed to a fire, for example where the fire impinges on a hydrogen storage tank at a location remote from the PRD. This may result in a tank burning through before the PRD is activated, particularly where the tank is made from a relatively fire sensitive material such as a carbon fibre composite. A failure to respond quickly to fire could result in catastrophic failure of the tank with disastrous consequences.

It is recognised that the number of PRDs required for protection of a gas storage vessel may be reduced by providing multiple trigger means arranged at different locations at the surface of the vessel with trigger transmitting means connected to one or more common PRDs. The trigger transmitting means may be in the form of a gas pipe. For example, there may be provided a heat sensitive trigger means comprising an elongate tube containing a displaceable material, wherein the elongate tube communicates with a plurality of individual heat sensors. The disposable material may engage a displaceable piston provided by each heat sensor. Displacement of the piston of any one of the heat sensors due to the melting or burning of its associated fusible or combustible elements may then allow displacement of the displaceable material within the elongate tube. Movement of the displaceable material within the elongate tube in response to any one of the heat sensors being actuated can cause the discharge means of the PRD to be exposed to gas pressure. The displaceable material in the elongate tube may comprise a plurality of balls. The balls may be arranged in groups adjacent each respective heat sensor such that at least one of the balls of each group engages the displaceable piston of a respective heat sensor mounted on a side opening of the tube. The groups of balls may be separated by elongate spaces or bushes to reduce the overall weight of the heat sensitive trigger means.

Where the gas storage vessel has a dual tank design, as is described above, such an elongate trigger tube may conveniently be protected inside the external tank, i.e. located between the internal tank and the external tank.

In addition to low fire resistance, current gas storage vessels (e.g. formed of carbon fibre composite materials) have quite a wide range of performance parameters, in particular their change with time of permeation rate and recurrence of small leaking through cracks etc. formed during its exploitation. Gas stored in the internal tank may leak out and result in a flammable mixture being formed between the tanks. In one set of embodiments this effect may be mitigated by initially filling any space between the tanks with an inert gas such as nitrogen. However leakage of the high pressure gas being stored may still occur. It is desirable to be able to control the level of leaks from a high pressure storage vessel. It has been recognised that the external (low pressure), preferably non-permeable, tank in a dual tank design may be used to provide for the controlled release of small gas leaks.

Furthermore, the leakage of gas from the internal tank into a space between the internal and external tanks is preferably monitored. In a preferred set of embodiments the vessel comprises a gas release valve arranged to release a mixture of gas and air from the space between the internal and external tanks only when the concentration of gas in the mixture is below a flammable level. For example, for hydrogen it is when its concentration in air is below 4% by volume. The flammability limit for other gases may be easily found in standard texts or calculated from empirical data. This can prevent the creation of a flammable mixture, and risk of combustion, between the internal and external tanks that could compromise the vessel strength. Otherwise the creation of a flammable mixture would require an increase in weight for the external tank to increase resistance to overpressure generated by combustion in the space between the tanks. Preferably the valve has an adjustable flow rate, for example a spring-loaded valve may be used. The safe release of potentially flammable mixtures can be particularly important when a vessel is used or stored in a confined structure, for example as part of a vehicle stored in a garage.

Preferably means are provided to count the frequency and/or duration of gas leaks. An external tank may therefore be used to control and/or monitor leaks originating from a higher pressure internal tank. Preferably the external tank comprises one or more gas release valves operable upon sensing a pressure above a threshold. Since the external tank contains gas at a relatively low pressure, any slight overpressure due to a leak from the internal (high pressure) tank can be easily sensed. The opening of the gas release valves in the external tank can be monitored to control the leakage rate throughout the whole surface of the vessel (e.g. to comply with regulations, codes and standards).

This feature is considered novel and inventive in its own right, irrespective of a dual tank design, and thus when viewed from a further aspect the present invention provides a gas storage vessel comprising one or more valve means for controllably releasing gas in response to an overpressure condition and means for monitoring the operation of the valve means. By controlling small leaks it is possible to prevent a larger accident from the leaks progressively (catastrophically) increasing. By monitoring the release of gas by the valve means, large scale leaks can be detected at an early stage.

Preferably, the vessel comprises an internal tank at least partially surrounded by an external tank, with the valve means communicating between the external tank and the atmosphere. It is an advantage that the valve means can be sheltered by the external tank whereas otherwise it could be difficult to accurately sense overpressure leakages, for example a hydrogen storage tank carried by a vehicle will have fluctuating leakages depending on acceleration/deceleration etc. The valve means may be used to control the release of gas-air mixture from a space between the internal and external tanks, as is described above. Pressure accumulation between the tanks can be avoided.

The valve means may, for example, be spring-loaded. When overpressure generated by leaks from the internal tank exceeds a predetermined level then the spring-loaded valve means preferably opens to release the overpressure. Of course, any large gas pressure build-up in the internal tank, for example in the event of a fire, will operate a safety pressure relief device for bulk gas discharge. Such a pressure relief device may be as described above and may further include a trigger means.

Any valve means and/or pressure relief device provided in communication with the internal tank, external tank, or space between the tanks, may be provided with a leak-tight membrane.

Preferably the monitoring means measures the frequency and/or duration of valve operation. In preferred embodiments the valve means may comprise a sensor to monitor its operation so that the number and/or duration of leakage events can be counted. The gas storage vessel or related gas storage system may further comprise a controller connected to such sensor(s) to monitor for gas leaks and optionally to provide an alert if the leak frequency and/or duration exceeds a safe threshold. Such a system advantageously allows for the controlled release of small leaks rather than allowing them to build up to such a pressure as to actuate a main pressure relief safety device unnecessarily.

The valve means may operate in response to an overpressure that is relatively small compared to the design pressure of the gas storage vessel, for example an overpressure of 0.01, 0.02, 0.05, 0.1, 0.5, 1, 2, 3, 4, 5, or up to 10 bar for the external tank, whereas the internal tank may contain, in use, gas at a pressure of 200, 350, 400, 500, 600, 700, 800, 900 or up to 1000 bar. Preferably the valve means are connected to a catalytic converter to clean the gas before it is released into the atmosphere.

Embodiments of the present invention extend to a hydrogen-powered vehicle comprising a hydrogen gas storage vessel and/or a pressure relief device for venting hydrogen as described hereinabove.

Various embodiments of the present invention will now be described, by way of example only, and with reference to the accompanying drawings, in which:

Fig. 1A shows a closed Pressure Relief Device, Fig. 1B shows an open Pressure Relief Device (high pressure) and Fig. 1C shows an open Pressure Relief Device (low pressure);

Fig. 2 is a longitudinal sectional view through a safety valve in a closed configuration;

Fig. 3 is a longitudinal sectional view through the safety valve of Fig. 2 in an open or activated configuration;

Fig. 4 is a sectional view of the valve of Fig. 2 on line A-A of Fig. 3;

Fig. 5 shows a triggering mechanism;

Fig. 6 shows a preferred embodiment of the present invention comprising a high pressure vessel and a low pressure tank in combination with a plurality of triggers and a preferred Pressure Relief Device; and

Fig. 7 is a longitudinal sectional view through another safety valve.

One implementation of a Pressure Relief Device 200 is shown in Figs. 1A-1C. Fig. 1A shows a closed Pressure Relief Device and Fig. 1B shows an open Pressure Relief Device wherein the storage pressure at release initiation is preferably high enough to compress the spring. Fig. 1C shows an open Pressure Relief Device at low pressure storage when pressure force cannot overcome the strength of the spring.

The high pressure end 204 of the Pressure Relief Device housing 202 is preferably connected at 206 in an appropriate way to a flammable gas release pipeline of a release triggering mechanism. A screw-bolt 208 is preferably screwed into the housing 202 using a hexahedron 210, which is a part of the screw-bolt 208, and sealed. The screw-bolt 208 preferably has a ring seal 212 to exclude leaking through the thread during the blowdown of flammable gas from the storage device. The screw-bolt 208 preferably has an axial channel 214 and side channels to provide the relief conduit for escaping gases. The screw-bolt 208 has an inclined surface 226 for the release of gases. Between the screw-bolt 208 and the housing 202 there is preferably provided a collar 216 and a bush 218 in a groove 228. The collar 216 and bush 218 preferably have ring seals 220 to exclude high mass flow rate in the beginning of release. To provide the escape of small unscheduled leaks appearing in the system and flowing through the release pipe line, the collar may have a pinhole (not shown in Figs. 1A-1C). There is preferably a gap between the screw-bolt 208 and the bush 218 to provide flow of gas at high mass flow rate through a sufficient venting area. A spring 222 is provided that pushes the bush 218 and the collar 216 (due to the friction between the collar seal and the bush) downwards to the bottom of the housing 202 at the normal (closed) Pressure Relief Device position seen in Fig. 1A.

The Pressure Relief Device 200 is preferably assembled by putting seals 212 on the screw-bolt 208 (two in total), seal 220 on the collar 216, and seal 220 on the bush 218; then pushing the collar 216 as far as possible to the bush 218 along the common axis; then putting the spring 222 into the screw-bolt 208; then putting the assembly of the collar 216 and the bush 218 on the spring 222; and finally screwing the screw-bolt 208 into the housing 202 to the end using the hexahedron 210 and similar part of the housing (not shown in Figs. 1A-C).

When a triggering mechanism allows flow into the housing, in case of high storage pressure the bush and the collar are preferably pushed up as shown in Fig. 1B. The collar 216 is preferably fixed at its top end position and the bush 218 preferably compresses the spring 222 due to the difference in pressure and is in a contact with the cylindrical part 224 of the screw-bolt 208. Slots in the bush 218 allow gas flow through them. Thus, in the event of high storage pressures both the bush 218 and the collar 216 are pushed up and the resulting aperture for release of gas is relatively small.

If the storage pressure is comparatively small then only the collar 216 is preferably moved up as the bush 218 remains at the same location or moves slightly up due to “strong” spring resistance to “low” pressure. Thus, in the event of low storage pressure e.g. when an accident has happened and the pressure was far below the maximum storage pressure, the release of gas starts from the beginning through a comparatively large area of the release route (aperture).

The Pressure Relief Device 200 may be fixed with a protective cover that is pushed out by gas in case of release or it can be movable out of another assembly similar to a piston-like dispersing member, as is shown in Figs 2-4. The dispersing member 18 is slidably mounted for movement between a retracted position, shown in Fig. 2, wherein the dispersing member 18 is located within the valve body 12, and an extended position, shown in Fig. 3, wherein the dispersing member 18 projects from the valve body 12. A lower end 20 of the dispersing member 18 is dimensioned to be a close sliding fit within the cylindrical housing 16 of the valve 10. A plurality of axially and/or circumferentially extending slots 22 are formed in the sides of the dispersing member 18 to define vent outlets, as seen in Fig. 4. A heat sensitive trigger means in the form of a fusible (or combustible) element 28, for example a plug formed from a relatively low melting point alloy, is mounted in a cap member 30 secured to the top of the valve body 12 to support the rupturable disk 26 and to retain the dispersing member 18 within the valve body 12.

When the safety valve 10 is exposed to a temperature over a predetermined maximum, for example in the event of a fire, the fusible element 28 melts and no longer provide support for the rupturable disk 26 which is therefore no longer able to support the force exerted by the dispersing member 18 under the action of the pressurised gas within the storage tank. The disk 26 ruptures and the dispersing member 18 slides within the cylindrical housing 16 of the valve body 12 to move to its extended position, projecting through the cap member 30. The stepped lower end of the dispersing member 18 abuts the cap member 30 to prevent the dispersing member 18 from completely leaving the valve body.

In the embodiment shown in Fig. 4, a plurality of longitudinally extending elongate slots 22 are formed at circumferentially spaced locations around the circumference of the dispersing member 18 defining a plurality of vent openings. The total area of the slots 22 is sufficient to provide rapid blowdown of the gas pressure within the tank to which the safety valve 10 is fitted while the small cross section of each individual slot 22 and the spacing of the slots 22 around the dispersing member 18 disperses and dilutes the escaping gas over a large area to resist combustion of the gas and, should combustion occur, preventing the formation of a long jet flame.

An implementation of a triggering mechanism is shown in Fig. 5. Pipelines from high pressure storage to the Pressure Relief Device are preferably isolated at normal operation conditions by seals 230 on a piston 232 . The piston position is preferably fixed by, for example, a metal alloy 234. The diameter of the piston 232 is preferably as small as possible to provide the blowdown of the storage vessel within the fire resistance time. A diameter of the metal alloy 234 is preferably relatively large to decrease the effective pressure. The piston 232 preferably has a widening 236 at the end. The piston widening 236 is preferably used to fix the piston 232 in its initial position. In an unillustrated embodiment a screw may be used to fix the piston. The piston widening 236 preferably protects a gap between the piston 232 and a channel where it moves from the metal alloy 234 when “pouring” it into the place and restricts the motion of the piston 232 by a stopper 238 when the metal alloy 234 is pushed out through a top and side orifices 240, available in the trigger body 242, after being melted e.g. by fire. Upstream of the piston 232 a sealing membrane can be installed (not shown) that can rest on the piston end.

There is described with reference to Fig. 6 a preferred embodiment that increases the fire resistance of a compressed fuel storage system and at the same time can easily control the level of leaks from a high pressure storage vessel.

This is achieved as follows. The storage system 250 preferably includes a high pressure vessel 252 which preferably contains a tank for compressed fuel 254 and a low pressure tank 256. The high pressure vessel 252 may be made of light and strong yet fire sensitive carbon-fibre, etc. The low pressure tank 256 is preferably made of a non-combustible material e.g. steel and is preferably protected from external and internal sides by fire resistant material e.g. intumescent coating/paint by way of internal fire protection 258 and/or external fire protection 259. Supports 260 are preferably provided between the high pressure vessel 252 and the low pressure tank 256 to reduce heat transfer from one to the other. A number of triggers 262 are preferably located on different or opposite sides of the tank to react to local fires and are preferably connected through a trigger tube 264 to a boss assembly 266 that preferably includes a pipe 268 to the Pressure Relief Device (not shown). The triggers 262 may be connected through a trigger tube as shown in Fig. 7. The trigger 262 preferably initiates the release of gas from the storage vessel through the pipe to the Pressure Relief Device.

In the embodiment shown in Fig. 7, the problem of sensing the exposure of a gas storage tank to fire at any location over the whole surface of the tank is solved by providing an elongate sensing tube 40 which accommodates multiple passive fire sensors 42A, 42B, 42C. Each fire sensor 42A, 42B, 42C comprises a piston 44 slidably mounted in a cylindrical housing 46 to be movable between a retracted position, wherein the piston 44 is located within the cylindrical housing 46, and an extended position, wherein at least a portion of the piston 44 projects from the housing 46, the piston 44 being retained in its retracted position by a fusible or combustible element 48. A first fire sensor 42A is mounted on a distal end of the elongate sensing tube 40. Further fire sensors 42B, 42C are mounted on side openings formed in the side wall of the sensing tube 40 at spaced locations along the length of the sensing tube 40.

A base portion 52 of the sensing tube 40 is connected to threaded connector 54 for connection to a vent outlet of the pressurised gas storage tank. A rupturable disk 56 is located between the base portion 52 of the sensing tube 40 and the threaded connector 54 for isolating the sensing tube 40 from high pressure gas within the storage tank.

A pressure relief passage branches 50 off from the sensing tube 40 immediately upstream of the rupturable disk 56. A safety valve 100 is mounted on an end of the pressure relief passage 50 comprising a cylindrical housing 116 within which a piston like dispersing member 118 is slidably mounted for movement between a retracted position wherein the dispersing member 118 is located within the valve body 112, and an extended position wherein the dispersing member 118 projects from the valve body 112. A lower end 120 of the dispersing member 118 is dimensioned to be a close sliding fit within the cylindrical housing 116 of the valve 100. A plurality of slots 122 are formed in the sides of the dispersing members 118 to define vent outlets 122 are will be described below in more detail. A further rupturable disk 126 is provided upstream of the dispersing member 118 for isolating the valve body 112 from the atmosphere. A protective cap 130 may be fitted over the end of the valve 100 to protect the rupturable disk 126. The cap may be sufficiently loose fitting to allow the cap 130 to be displaced by the dispersing member 118 when the dispersing member 118 moved to its extended position when the heat sensitive trigger means is activated. The rupturable disk 56 located upstream of the safety valve 100 isolates the dispersing member 118 of the valve 100 from high pressure gas within the storage tank until one of the multiple fire sensors 42A, 42B, 42C is triggered.

Returning to Fig. 6, a mechanism is preferably provided to control a leakage rate throughout the whole surface and connections of the high pressure vessel 252. The mechanism is preferably installed on the low pressure tank 256 that is made of leak-free (i.e. gas impermeable) material. When overpressure generated by leaks exceeds a predetermined level then the spring-loaded valve 270 of the mechanism preferably opens to release the overpressure via a small leak pipe 272. At this moment the switch-sensor 274 preferably registers the opening. The switch-sensor 274 is preferably connected to an electronic device (not shown) that sends a signal to change the storage system if the frequency of the switch-sensor 274 is over an established limit or it does not return to its initial position (e.g. the leak is quite strong to let switch close). These periodic small leaks are preferably directed out or to a catalytic converter through the small leak pipe 272.

Although the present invention has been described with reference to preferred embodiments, it will be apparent to those skilled in the art that various changes in form and detail may be made without departing from the scope of the invention as defined in the accompanying claims.

Claims

1. A gas storage vessel comprising an internal tank that is at least partially surrounded by an external tank having a higher fire resistance than the internal tank, and a pressure relief device, wherein the internal tank is designed to store gas at a higher pressure than the external tank and wherein the external tank is formed of incombustible material.

2. A vessel as claimed in claim 1, wherein the external tank is made of a material that is impermeable to gas.

3. A vessel as claimed in claim 1 or 2, wherein the external tank is made of steel.

4. A vessel as claimed in any preceding claim, wherein the external tank is covered by fire resistant materials from outside and/or inside.

5. A vessel as claimed in any preceding claim, wherein the internal tank is used to store hydrogen gas.

6. A vessel as claimed in any preceding claim, wherein the internal gas storage tank is made of composite material such as carbon fibre reinforced polymer or resin.

7. A vessel as claimed in any preceding claim, wherein, in use, the internal gas storage tank stores a gas at a first pressure and the external tank stores a gas at a second, lower pressure.

8. A vessel as claimed in any preceding claim, wherein there is a gas pressure difference between the internal and external tanks, in use, of at least 200, 300, 400, 500, 600, 700, 800, 900, 920, 940, 960, 980 or 990 bar.

9. A vessel as claimed in any preceding claim, wherein the internal tank can withstand pressures up to 1000 bar.

10. A vessel as claimed in any preceding claim, wherein the external tank is arranged to provide for the controlled release of small gas leaks.

11. A vessel as claimed in any preceding claim, wherein the internal tank is arranged so as to be entirely contained within the external tank.

12. A vessel as claimed in any preceding claim, wherein the pressure relief device communicates with the internal and/or external tank.

13. A vessel as claimed in any preceding claim, wherein a space between the internal and external tanks is at least partially filled with inert gas such as nitrogen.

14. A vessel as claimed in any preceding claim, comprising means for monitoring the leakage of gas from the internal tank into a space between the internal and external tanks.

15. A vessel as claimed in any preceding claim, comprising a gas release valve arranged to release a mixture of gas and air from a space between the internal and external tanks only when the concentration of gas in the mixture is below a flammable level.

16. A vessel as claimed in claim 15, wherein the gas release valve is arranged to operate when a concentration of hydrogen in the mixture is below 4% by volume.

17. A vessel as claimed in claim 15 or 16, wherein the gas release valve is spring-loaded.

18. A vessel as claimed in any preceding claim, wherein the external tank comprises one or more gas release valves operable upon sensing a pressure above a threshold.

19. A vessel as claimed in claim 18, wherein the external tank comprises means for monitoring the operation of the gas release valve(s).

20. A vessel as claimed in claim 19, wherein the monitoring means is arranged to count the frequency and/or duration of gas leaks.

21. A vessel as claimed in claim 19 or 20, wherein the monitoring means measures signals from switch sensor(s) associated with the gas release valve(s).

22. A vessel as claimed in any preceding claim, wherein the pressure relief device comprises gas discharge means actuable by gas pressure to move from a closed position to a first open position having a discharge area A_1 and biasing means arrange to move the discharge means against the gas pressure to a second open position having a discharge area A_2 greater than A_1.

23. A vessel as claimed in claim 22, wherein the pressure relief device further comprises at least one heat sensitive trigger means, such as a fusible or combustible member.

24. A hydrogen-powered vehicle comprising a storage vessel according to any preceding claim for the onboard storage of hydrogen gas.

25. A gas storage vessel comprising one or more valve means for controllably releasing gas in response to an overpressure condition and means for monitoring the operation of the valve means.

26. A vessel as claimed in claim 25, wherein the monitoring means is arranged to count the frequency and/or duration of gas leaks.

27. A pressure relief device (PRD) for venting gas from a storage vessel, comprising gas discharge means actuable by gas pressure to move from a closed position to a first open position having a discharge area A_1 and biasing means arrange to move the discharge means against the gas pressure to a second open position having a discharge area A_2 greater than A_1.

28. A PRD as claimed in claim 27, wherein there is provided two-way movement of the discharge means between the first and second open positions.

29. A PRD as claimed in claim 27 or 28, further comprising at least one heat sensitive trigger means arranged to isolate the discharge means from gas pressure in the vessel.

30. A PRD as claimed in claim 29, wherein the heat sensitive trigger means comprises a fusible or combustible member.

31. A PRD as claimed in any of claims 27-30, wherein the discharge means is held in the closed position by a spring biasing means.

32. A PRD as claimed in any of claims 27-31, wherein the discharge means comprises a piston-like dispersing member provided with at least one vent opening formed therein.

33. A PRD as claimed in claim 32, wherein the dispersing member is slidably mounted within a body of the device to be movable between a retracted position, wherein at least one vent opening is obscured by a portion of the device body, and an extended position, wherein the dispersing member projects from the body to expose its vent opening(s).

34. A PRD as claimed in claim 32 or 33, wherein the vent opening(s) in the discharge means comprise(s) one or more axially extending slots extending through a side wall of the dispersing member.

35. A pressurised gas storage system comprising a storage vessel formed of fibre-reinforced polymer, a temperature or heat sensitive trigger means, and a pressure relief device (PRD) arranged to be exposed to gas pressure from the storage vessel upon actuation of the temperature or heat sensitive trigger means.

36. A system as claimed in claim 35, wherein the PRD has a variable discharge area comprising gas discharge means actuable by gas pressure to move from a closed position to a first open position having a discharge area A_1 and biasing means arrange to move the discharge means against the gas pressure to a second open position having a discharge area A_2 greater than A_1.

37. A system as claimed in claim 36, wherein there is provided two-way movement of the discharge means between the first and second open positions.

Fig. 1A

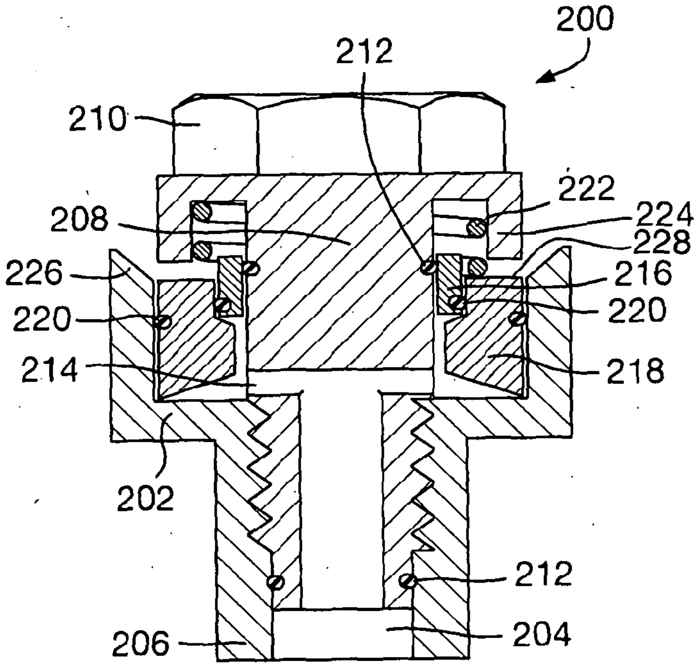


Fig. 1B

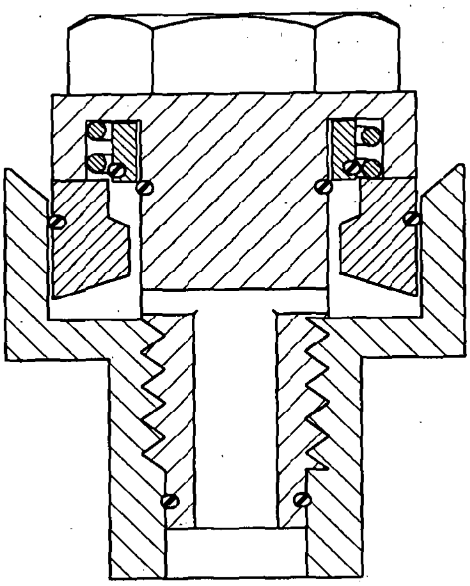


Fig. 1C

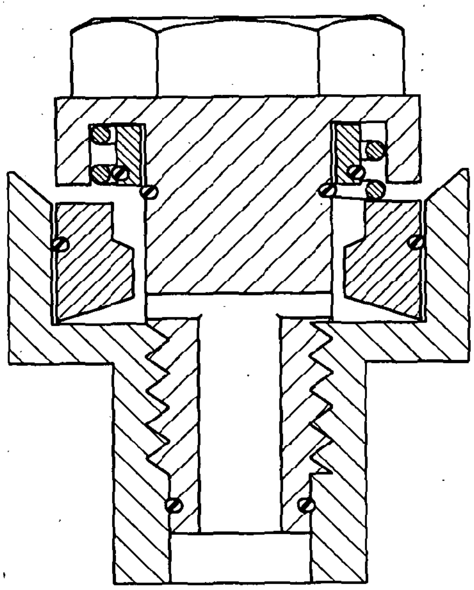


Fig. 2

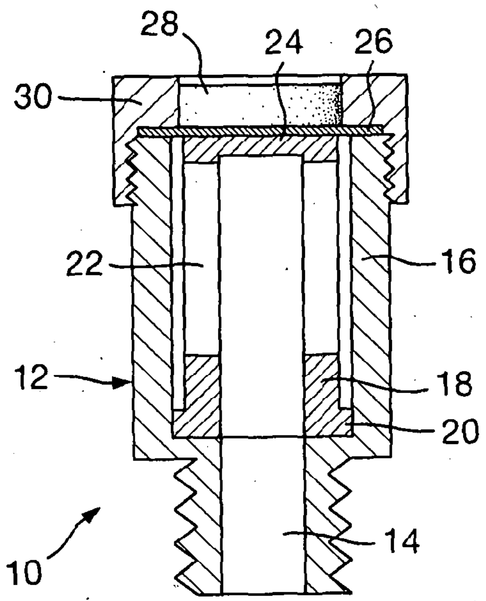


Fig. 3

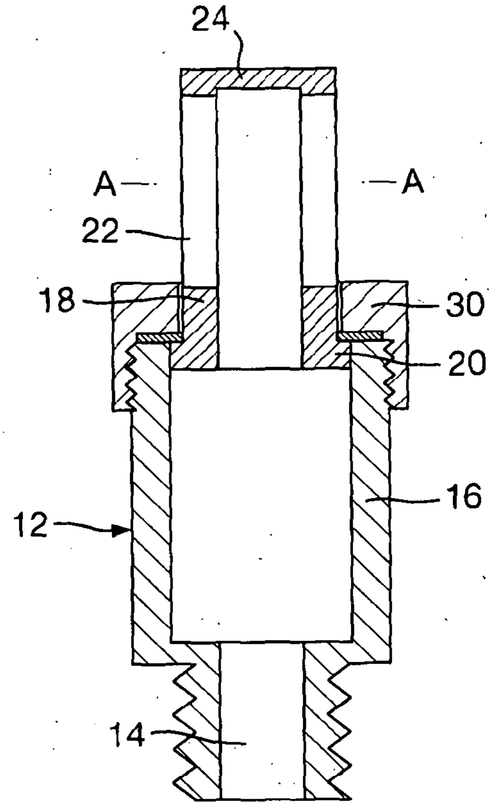


Fig. 4

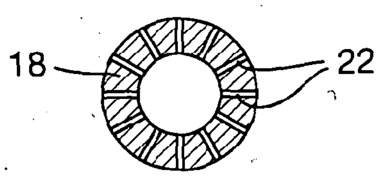
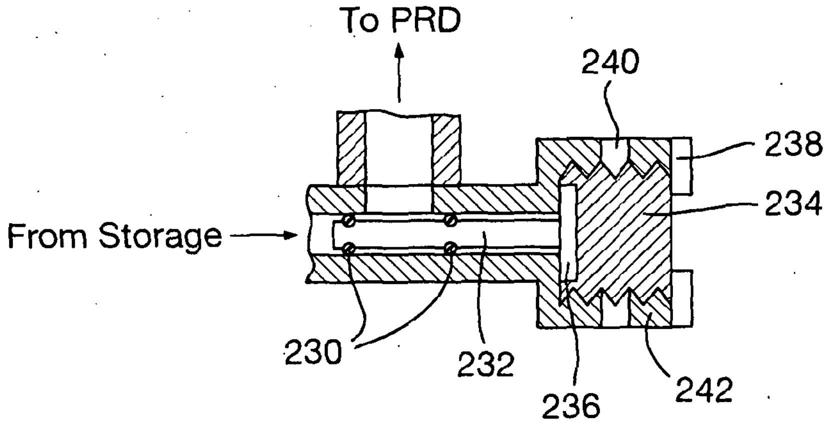


Fig. 5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From Storage
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Fig. 6

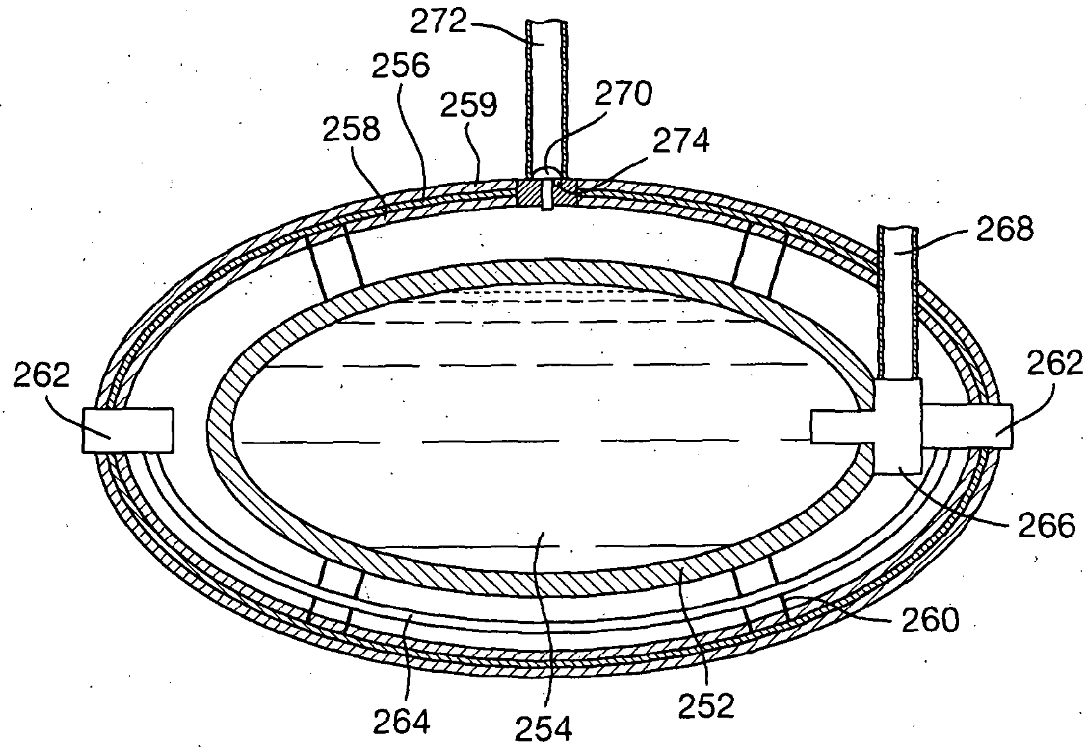
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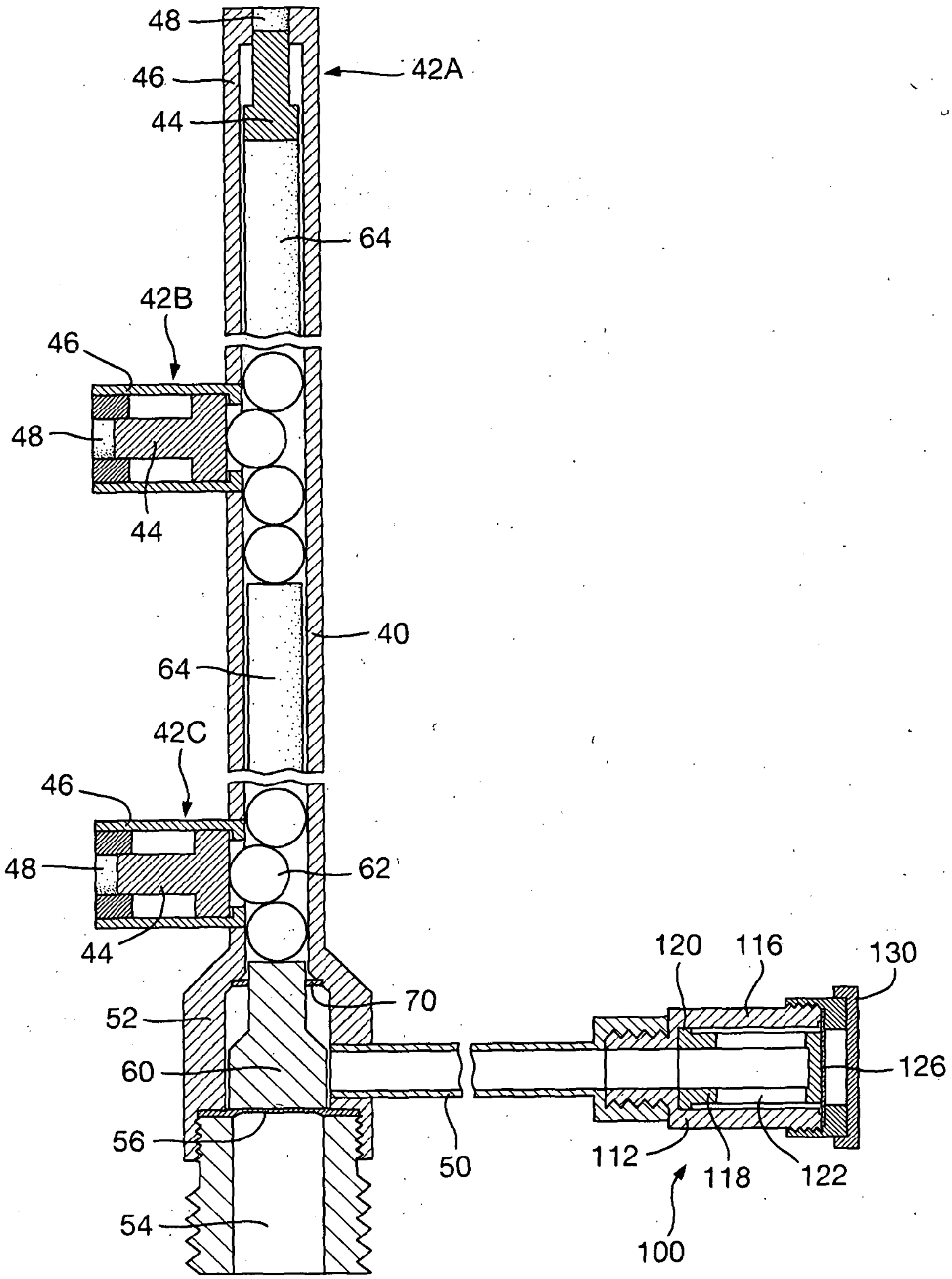
Fig. 7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