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(54) **Title**: CONVERSION OF AMMONIA INTO NITROGEN AND HYDROGEN

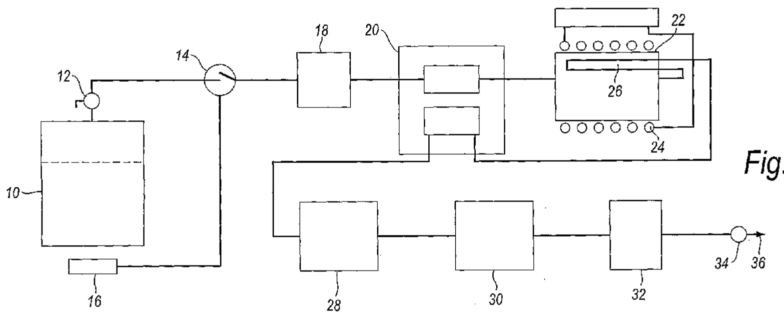

Fig.1

(57) **Abstract**: An apparatus for converting ammonia gas into nitrogen and hydrogen gases includes: (a) a heater (16) for heating ammonia to convert it into gas; (b) a reactor (22) including a first path for containing a catalyst for facilitating conversion of ammonia into nitrogen and hydrogen; (c) a first heat exchange arrangement (20) outside the reactor (22) for heating the ammonia before it is passed into the reactor (22), and (d) a second heat exchange arrangement (26) in the reactor (22) including a second path in the reactor (22) for passing the nitrogen and hydrogen gases through the reactor (22) in heat exchange relationship with the first path to effect further heating of the ammonia.

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Conversion of Ammonia into Nitrogen and Hydrogen

This invention relates to a method and apparatus for converting ammonia into nitrogen and hydrogen gas, a process commonly referred to as "cracking". The invention is concerned particularly, but not exclusively, with such a method and apparatus for the purpose of providing hydrogen gas for a fuel cell. In another aspect the invention relates to an apparatus for storing ammonia.

The conversion of liquid ammonia into nitrogen and hydrogen gas has been widely practised for many years. In different applications, there may be different requirements for the process and/or apparatus. The present invention is especially, but not exclusively, concerned with conversion on a relatively small scale using compact apparatus able to operate at a remote location, where it may be necessary to store the ammonia. Such a process and apparatus may for example be capable of generating one thousand to ten thousand litres per hour of hydrogen gas.

It is relatively straightforward to provide a process and apparatus capable of this kind of performance if no regard need be had to the economics or efficiency of the process or the periods of time that can be allowed between maintenance visits. Difficulties arise, however, when those considerations are taken into account. Some of those difficulties will be briefly described below.

When ammonia is being converted into nitrogen and hydrogen (an endothermic reaction), the temperature at which the conversion occurs has a significant impact on the amount of ammonia that remains unconverted. For example at 6 bar and 650 Celsius the ammonia remaining after the reaction may be around 0.2%, whilst at a temperature of 850 Celsius the amount of ammonia remaining may be around 500 ppm. From that point of view it is desirable for the conversion of the ammonia to take place at high temperature.

There are, however, some problems with carrying out the reaction at high temperature. One problem is that additional heat energy must be provided to raise the temperature of the ammonia gas, and that tends to make the process inefficient, even if the products of the conversion are used to heat the incoming ammonia. A further problem is that the lifetime of various components in the system is reduced as a result of increased corrosion with increased operating temperatures. Such corrosion can, for example, arise from water vapour in the ammonia gas, from hydrogen embrittlement and from exposure of metal components to oxygen. Metal nitrides can also be created by reaction of ammonia with metal surfaces.

In some applications the presence of significant amounts of ammonia in the gaseous products may not be problematic, but in other cases it is and it is then necessary to provide extra equipment to remove the ammonia involving extra cost and possibly extra energy and/or more frequent maintenance to replace filters or the like.

Various processes for converting ammonia into hydrogen and nitrogen are known and each have their own advantages and disadvantages. For example, using a catalytic process for conversion and heating the ammonia prior to its conversion can be made a fairly efficient process, but it is not one that can be started instantly to meet an immediate demand for hydrogen. Using a microwave generator for the conversion is known and has the advantage that it can provide hydrogen on demand, but that process tends to be less efficient.

It is an object of the present invention to provide a method and apparatus for converting liquid ammonia into nitrogen and hydrogen gas, and for storing ammonia, in which one or more of the problems referred to above are mitigated.

According to a first aspect of the invention there is provided an apparatus for converting ammonia gas into nitrogen and hydrogen gases, the apparatus including:

(a) a heater for heating ammonia to convert it into gas;

(b) a reactor including a first path for containing a catalyst for facilitating conversion of ammonia into nitrogen and hydrogen;

(c) a first heat exchange arrangement outside the reactor for heating the ammonia before it is passed into the reactor, and

(d) a second heat exchange arrangement in the reactor including a second path in the reactor for passing the nitrogen and hydrogen gases through the reactor in heat exchange relationship with the first path to effect further heating of the ammonia.

By providing two heat exchange arrangements, one in the reactor and the other outside the reactor, it becomes possible to make more efficient use of the hot gases produced during the cracking of the ammonia and to keep the maximum temperature in the reactor lower.

The first heat exchange arrangement may comprise a pipe-in-pipe arrangement, one of the pipes being for passing ammonia into the vessel and the other of the pipes being for receiving the nitrogen and hydrogen gases from the reactor. Preferably an inner pipe is mounted coaxially within an outer pipe. Preferably the pipe-in-pipe arrangement follows a tortuous path. For example the path may be of a serpentine shape or of a coil shape.

Preferably the second heat exchange arrangement is formed by a generally solid body of thermally conducting material within which the first and second paths are provided, the thermally conducting solid body providing a path for heat to be exchanged between the second path and the first path. Such an arrangement enables good heat transfer to be achieved. It should be understood that while it is within the scope of the invention for the generally solid body to be formed as a single solid piece, it is within the scope of the invention for the body to be made in several pieces and to have parts which are not solid. In an embodiment of the invention described below the reactor is formed from a core over which a sleeve is fitted and the core has a central opening for receiving a coaxial pipe.

Preferably a heater, which may be an electric heater, is provided for heating the generally solid body of thermally conducting material. The heater may be a radiant heater but, as explained in more detail below, there are particular advantages in using induction heating to heat the generally solid block and the heater is therefore preferably an induction heater.

In an especially preferred embodiment, a multiplicity of passageways are formed in the generally solid body, the passageways including one or more sets of passageways extending between a first end region of the solid body and a second end region of the solid body opposite the first end region, the passageways in the or each set of passageways being approximately parallel to one another, connected in series with one another, and defining the first and second paths. In such an arrangement, it becomes possible to provide relatively long gas paths within a compact reactor and to provide good heat exchange within the reactor. Preferably, there are a plurality of sets of passageways. In an embodiment of the invention described below there are eight sets of passageways. The sets of passageways may provide respective parallel flow paths for the gases. While reference is made to the generally solid body having first and second end regions, it should be understood that the body is not necessarily elongate, although that is preferred. For example, it is within the scope of the invention, although not preferred, to provide a generally solid body of circular, cylindrical shape having a diameter greater than its length.

Preferably the or each set of passageways includes a chamber, preferably elongate, for containing catalyst. The catalytic reaction may take place in a space of any of a wide variety of shapes but an elongate chamber, preferably extending between the opposite end regions of the reactor is preferred. The downstream end of the chamber for containing catalyst is preferably closed by a gas permeable closure for allowing the passage of gas while obstructing the passage of a solid catalyst.

Preferably the or each set of passageways include one or more upstream passageways connected upstream of the chamber. More preferably, the or each set of passageways include a first upstream passageway extending from the first end region of the generally solid body to the second end region and a second upstream passageway connected in series with the first upstream passageway and extending from the second end region of the solid body to the first end region. By providing such passageways upstream of the chamber in which the cracking of ammonia takes place in use, it is possible to arrange for substantial heat transfer into the ammonia during its passage through the reactor and before it is cracked.

Preferably, the or each set of passageways include a downstream passageway connected downstream of the chamber. By providing such a passageway downstream of the chamber in which the cracking of ammonia takes place in use, it is possible to arrange for substantial heat transfer from the gases produced, in use, from cracking during their passage through the reactor after cracking.

Preferably the generally solid body comprises a core and a sleeve fitted around the core, some of the passageways, preferably upstream passageways, being defined by channels formed between the periphery of the core and the sleeve. That provides a simple way of forming the channels and enables them to be in close thermal proximity to a heating device surrounding the generally solid body. Preferably, the channels formed between the periphery of the core and the sleeve include at least one pair of channels which are connected to one another at the first end region of the generally solid body. Preferably the pair of channels define the first and second upstream passageways.

At least some of the downstream passageways may be formed by bores in the core of the solid body. The catalyst chambers are preferably formed by bores in the core of the solid body.

The plurality of sets of passageways are preferably angularly spaced, more preferably approximately equiangularly spaced, around the longitudinal axis of the generally solid body.

The generally solid body is preferably elongate and of approximately circular cross-section. Preferably the body is orientated with the longitudinal axis of the body vertical.

The generally solid body preferably has a central portion extending from the first end region to the second end region, the central portion defining an inlet pipe for conveying ammonia to the one or more sets of passageways and an outlet pipe for conveying nitrogen and hydrogen gases out of the reactor. Preferably the inlet pipe enters the generally solid body in the first end region, extends through the central portion of the body and opens into a chamber in the second end region of the solid body. The chamber preferably extends radially outwardly beyond the central portion of the end region of the body, preferably to a peripheral region of the body. The outlet pipe preferably extends through the central region of the body around the inlet pipe and leaves the generally solid body in the first end region of the generally solid body. The inlet and outlet "pipes" may be formed as separate members fitted into the body or may be formed integrally with the body.

By adopting at least some of the features referred to above, it becomes possible to make the overall volume of the generally solid body small. Preferably its overall volume is less than 10,000 cm^3 and more preferably less than 3,000 cm^3.

In an especially preferred embodiment, the reactor is housed in a chamber within a larger vessel. The vessel may include an outer storage chamber for storing gases produced in the conversion of the ammonia, the chamber housing the reactor being disposed within the outer storage chamber. Such an arrangement can be especially compact.

In an especially preferred embodiment, the chamber housing the reactor is a low pressure chamber. By placing the reactor in a low pressure chamber heat losses from the chamber are reduced and the rates of corrosion of parts of the reactor are also reduced. The pressure in the chamber is preferably less than 0.3 bar and more preferably less than 0.15 bar. In an embodiment of the invention described below it is 0.1 bar.

The top of the inside of the chamber housing the reactor is preferably spaced from the top of the reactor. Preferably the top of the inside of the chamber housing the reactor is spaced from the top of the reactor by more than 25 mm, and more preferably more than about 50 mm. In an embodiment of the invention described below the spacing is about 75 mm. That tends to reduce heat loss from the reactor, especially when the chamber is at low pressure.

The first heat exchange arrangement is preferably disposed inside the vessel. That enables an efficient and compact design to be achieved.

The vessel is preferably itself compact, preferably having an interior volume of less than 1 m^3 and more preferably less than 0.5 m^3.

The apparatus described above is especially suited to operation in conjunction with a hydrogen fuel cell, for example a PEM fuel cell stack. Such fuel cells are known *per se*, but the present invention enables a system to be provided for generating modest amounts of electricity reliably and from a commonly available starting material of ammonia. Thus the present invention further provides an electricity generating system including a hydrogen fuel cell for generating electricity from hydrogen and an apparatus according to any preceding claim for generating hydrogen.

Preferably the fuel cell is arranged to provide electrical power for operating the apparatus for converting ammonia into hydrogen and nitrogen. In that case the only external supply that the system requires is a supply of ammonia.

In an especially preferred form of the invention, the entire system, including the fuel cell, can be fitted inside a portable container, preferably a standard freight container. The freight container is preferably one having a length of less than 3.5 metres and more preferably less than 3 metres. The freight container may be one having a length of about 2.4 metres, that is one known as an "8 ft" container. As will be understood where reference is made to a standard freight container that is referring to a container having standard dimensions and ISO corner castings at its corners to enable it to be handled and transported easily by ISO load handling and transporting equipment.

One particularly suitable application for the invention is to power a telecommunications mast such as that employed in a mobile telephone system, especially where that mast is in a rather remote location. Thus the system is preferably suitable for providing power to a mobile telephone mast, more preferably the system is suitable for providing the base-load power to a mobile telephone mast, that is the system is the principal or only power source for the mobile telephone mast, rather than just a back-up power source. Typically an ammonia cracker embodying the invention is able to produce hydrogen at a rate in the range of 300 to 3,000 litres per hour at STP.

When the mast is described as being in a remote location, it will be understood that a remote location may be one where the mast is not connected to an electricity grid or is connected to an unreliable electricity grid. That "remote location" may be in a populated area such as a village or a town. The mast may be connected to a small local grid or micro-grid, i.e. a collection of small generators for a collection of users in close proximity.

The first aspect of the invention has been described above with reference to an apparatus for converting ammonia gas into nitrogen and hydrogen gases, but it can also be embodied in a method. Thus according to the first aspect of the invention, there is also provided a method of converting liquid ammonia into nitrogen and hydrogen gases, the method including the following steps:

(a) heating the liquid ammonia to convert it into gas;

(b) passing the ammonia gas along a first path through a reactor containing a catalyst, causing conversion of the ammonia gas into nitrogen and hydrogen gases, and

(c) passing the nitrogen and hydrogen gases generated in the reactor through a heat exchange arrangement to effect heating of the ammonia before it is passed through the reactor,

wherein the method further includes the step of

(d) passing the nitrogen and hydrogen gases along a second path through the reactor vessel in heat exchange relationship with the first path to effect further heating of the ammonia.

It is not an essential feature of the invention that all the ammonia gas is converted in the reactor and indeed it is likely that at least a small proportion of the gases leaving the reactor will be ammonia.

Preferably the ammonia gas is heated as it passes along the first path. At least some of the heating may be provided by radiant heating. More preferably, at least some of the heating is provided by induction heating. Where reference is made in this specification to heating gas or gases by induction heating, it should be understood that the induction heating may not heat the gas directly but may, for example, heat a solid body which in turn heats the gas. The use of induction heating is especially advantageous in the present invention because, unlike a radiant heater, the induction heater need not be at an especially high temperature compared to what is being heated. In the present invention, the induction heater may be employed to heat the reactor by generating eddy currents in the reactor.

In an especially preferred form of the invention, the highest temperature of the reactor, including any heater associated with the reactor for heating the gases, is less than 200 Celsius above the highest temperature of the gases as they pass through the reactor. In such a case it becomes much easier to extract heat from the gases generated from cracking of the ammonia, because the heat source may be only slightly hotter than those gases.

Preferably the conversion of the ammonia is carried out at a pressure above the ambient pressure. Increasing the pressure of the system allows more gas to be stored in a smaller volume, however if the pressure is too high then some of the gases, particularly the ammonia, may start to condense. Storage of gases may be required, for example, to allow a buffer, to prevent pressure or flow transients or to allow restart of a generator system including the reactor using the stored gases. Preferably the pressure of the gases in the reactor is between 3 bar and 9 bar. In an embodiment of the invention described below the pressure in the reactor is about 6 bar. Lower pressures will reduce the ammonia slip concentration, i.e. the concentration of ammonia after the reactor, but increased pressures may still be preferred if they allow the use of filters or molecular sieves downstream of the reactor in particular to separate the nitrogen from the hydrogen stream, which may improve overall efficiency.

The ammonia to be cracked is preferably heated to a temperature about 500 Celsius after passing through the first and second heat exchangers. In an embodiment of the invention described below the ammonia is heated to a temperature of about 600 Celsius after passing through the heat exchangers.

The heater that is preferably provided for heating the solid body of the reactor preferably further raises the temperature of the ammonia to a temperature in the range of 600 to 1,000 Celsius and more preferably 650 to 950 Celsius and yet more preferably 650 to 900 Celsius. For some applications a relatively low temperature range of 650 to 750 Celsius may be preferred whilst for other applications a higher temperature range of 750 to 950 Celsius may be preferred. In some applications a temperature range of 750 to 900 Celsius may be preferred. The highest temperature reached by any of the gases is preferably less than about 100 Celsius different from, and lower than, the highest temperature of any part of the reactor.

The method according to the first aspect of the invention may be carried out using an apparatus of any of the forms defined above.

The method according to the first aspect of the invention as defined above may be carried out in conjunction with a further process for converting ammonia into nitrogen and hydrogen gases. In an embodiment of the invention described below a second process is used to convert small amounts of ammonia remaining after the ammonia has been passed through the reactor. The further process may also be used in another way in which the method includes the following steps:

(a) converting the ammonia into nitrogen and hydrogen gases by means of a first process;

(b) preparing to operate a second process for converting the ammonia, while the first process is operating, the second process being a method according to the first aspect of the invention as defined above; and, subsequently,

(c) converting the ammonia into nitrogen and hydrogen gases by means of the second process.

Adopting a method of this kind can be advantageous, for example, if the first process is able to start up quickly to meet an urgent requirement for ammonia, since the thermal cracking process in the reactor is likely to take some time to start up.

It may be acceptable for the first process to be a less efficient process or a less favourable process in some other respect because it may be required only to operate until the second process is fully operational. Thus the method may include the step of stopping the conversion of ammonia by means of the first process. The second process would then continue, with the second process stopping at a later time, for example when no more hydrogen was required.

Another possibility is that the first process continues to operate after the second process has started, with at least some products of the second process being subsequently subjected to the first process. In this case the role of the first process changes from a start up role to a secondary cracking role. The first process may for example include exposing ammonia to high frequency wave energy, such as microwaves. The high frequency is preferably a frequency greater than 100Mhz. Preferably the high frequency corresponds to absorption bands for the ammonia molecule. For example the high frequency may be around 23.8 GHz.

The generally solid body of thermally conducting material within which cracking and heat exchange are carried out in preferred embodiments of the first aspect of the invention is in itself a very special and advantageous feature that can be used not only in accordance with the first aspect of the invention but also in other ways. Thus according to a second aspect of the invention, there is provided an apparatus for converting ammonia gas into nitrogen and hydrogen gases, the apparatus including a generally solid body of thermally conducting material within which a multiplicity of passageways are formed, the passageways including one or more sets of passageways extending between a first end region of the solid body and a second end region of the solid body opposite the first end region, the passageways in the or each set of passageways being approximately parallel to one another, connected in series with one another, and including at least one passageway for containing a catalyst for catalysing the conversion of ammonia gas into nitrogen and hydrogen gases.

The provision of a vessel including a storage chamber and an inner chamber containing a reactor in preferred embodiments of the first aspect of the invention is in itself a very special and advantageous feature that can be used not only in accordance with the first aspect of the invention but also in other ways. Thus according to a third aspect of the invention, there is provided an apparatus for converting ammonia gas into nitrogen and hydrogen gases, the apparatus including a vessel including an outer storage chamber for storing gases produced in the conversion and an inner chamber containing a reactor for converting ammonia gas into nitrogen and hydrogen gases.

The provision of a reactor located within a low pressure chamber in preferred embodiments of the first aspect of the invention is in itself a very special and advantageous feature that can be used not only in accordance with the first aspect of the invention but also in other ways. Thus according to a fourth aspect of the invention, there is provided an apparatus for converting ammonia gas into nitrogen and hydrogen gases, the apparatus including a vessel including a reactor for converting ammonia gas into nitrogen and hydrogen gases, the reactor being located within a low pressure chamber contained within the vessel.

The provision of a method of cracking ammonia in a reactor in which the highest temperature of the reactor is less than 200 Celsius above the highest temperature of the gases as they pass through the reactor, as described above in respect of the first aspect of the invention, is in itself a very special and advantageous feature that can be used not only in accordance with the first aspect of the invention but also in other ways. Thus according to a fifth aspect of the invention, there is provided a method of converting liquid ammonia into nitrogen and hydrogen gas, the method including the following steps:

(a) heating the liquid ammonia to convert it into gas;

(b) passing the ammonia gas along a path through a reactor containing a catalyst, causing conversion of the ammonia gas into nitrogen and hydrogen gases, and

(c) heating the gases as they pass along the first path through the reactor,

wherein the highest temperature of the reactor, including any heater associated with the reactor for heating the gases, is less than 200 Celsius above the highest temperature of the gases as they pass through the reactor.

The use of induction heating to heat the ammonia as described above in respect of the first aspect of the invention, is in itself a very special and advantageous feature that can be used not only in accordance with the first aspect of the invention but also in other ways. Thus according to a sixth aspect of the invention, there is provided a method of converting liquid ammonia into nitrogen and hydrogen gas, the method including the following steps:

(a) heating the liquid ammonia to convert it into gas;

(b) passing the ammonia gas along a path through a reactor containing a catalyst, causing conversion of the ammonia gas into nitrogen and hydrogen gases, and

(c) heating the gases as they pass along the first path through the reactor,

wherein at least some of the heating carried out on the gases as they pass along the first path through the reactor is induction heating.

The use of a first cracking process to substitute for a second process, for example during start up of cracking, is in itself a very special and advantageous feature that can be used not only in accordance with the first aspect of the invention but also in other ways. Thus according to a seventh aspect of the invention, there is provided a method of converting liquid ammonia into nitrogen and hydrogen gas, the method including the following steps:

(a) converting the ammonia into nitrogen and hydrogen gases by means of a first process;

(b) preparing to operate a second process for converting the ammonia, while the first process is operating; and, subsequently,

(c) converting the ammonia into nitrogen and hydrogen gases by means of the second process.

An apparatus according to an aspect of the invention may be used in unattended installations in remote areas or in densely populated areas where there is little security. Such installations need to store a supply of ammonia to use as fuel. The ammonia may, for example, be anhydrous ammonia. Alternatively, unattended installations may need to store propane or other fuels. In such areas conventional generators may be vulnerable to fuel theft.

Storage of ammonia may be subject to regulations. It may be that regulations for static storage tanks are different to regulations for transportable storage tanks. Thus while an installation may be supplied from transportable tanks, with the tanks being replaced when they are empty, it is preferable for the installation to be supplied from a static tank that is refilled.

Refuelling of the installation may be carried out by unskilled workers, that is workers who are not sufficiently qualified to carry out maintenance. Advantageously, sufficient access to the installation can be given to those workers to enable them to refuel the installation whilst not allowing them to remove fuel or perform other maintenance tasks. However, maintenance tasks, including draining the stored ammonia, may need to be performed on the installation and thus, advantageously, complete access to the installation can be given to maintenance personnel.

In areas of low security it is possible that an installation may be determinedly attacked by fuel thieves. Advantageously the installation is able to withstand such an attack. Preferably the installation is housed in a secure container. The container may be made of metal and may be in the form of a standard freight container. Preferably the container may be securely fastened in a closed position, i.e. locked shut.

Preferably there is no pipework, outside the container, that, if breached, would allow ammonia to be removed from the container. Thus the inlet pipe is preferably fitted with a non-return or one-way valve, situated within the secure container, so that even if any cap or stopper on the end of the inlet pipe is breached, no ammonia can be withdrawn through the pipe. Such a one-way valve may also prevent unauthorised withdrawal of ammonia from the installation by a person who has gained the means to access the installation for refuelling.

Advantageously, the filling port is in a lockable box or under a lockable cap. Thus it may be that only refuelling personnel have access to the filler port. That may increase the difficulty of theft and may prevent unauthorized personnel filling the tank with the wrong chemical. Refuelling companies may wish to ensure full stewardship over any chemicals delivered. A separate cover and locking mechanism may enable such companies to ensure that only their trained staff have access to the filler port.

The take-off, or drain, pipe is preferably fitted with a manual shut-off valve situated within the secure container. Thus, even if the integrity of the exposed end of the take-off pipe is damaged, the manual shut-off valve will prevent withdrawal of ammonia through the take-off pipe.

Preferably ammonia cannot be removed from the installation without first breaching the integrity of the secure container. It will be appreciated that a secure container may be more resistant to attack than an exposed pipe would be.

According to an eighth aspect of the invention there may be provided an apparatus for storing liquid ammonia, the apparatus comprising an ammonia storage tank within a container, the ammonia tank being connected to a filling port that is accessible without opening the container.

The ammonia tank may be connected to a take-off pipe comprising a valve, the valve being inaccessible when the container is closed.

The container may be a secure container.

The ammonia tank may be connected to the filling port via a one-way valve that prevents flow from the tank to the filling port.

The apparatus may comprise means for measuring the amount of ammonia in the tank.

The measuring means may comprise a load cell on which the tank rests.

The measuring means may comprise a level sensor.

The measuring means may be connected to a data port. The data port may be accessible without opening the container.

The measuring means may be connected to the data port by wireless data transmission means or by wired data transmission means.

The measuring means may be connected to a wireless data transmitter, for example, a mobile phone mast. The wireless data transmitter may be inside or outside the container. The wireless data transmitter may be capable of transmitting data to a point outside the container. The wireless data transmitter may be capable of transmitting data to a control centre, for example a control centre at another location and even in another country.

The filling port may be in a lockable housing on the outside of the container. The data port may be in a lockable housing on the outside of the container.

The lockable housing may be a lockable box. Alternatively the lockable housing may be a lockable flap or cap.

Preferably the data port and the filling port are in the same lockable housing.

When the lockable housing is described as being on the outside of the container it will be understood that the lockable housing is positioned so as to be accessible from outside the container.

The lockable housing may, for example, be lockable by means of a key operated lock, or by means of a combination lock or a keypad operated lock. The secure container may, for example, be lockable by means of a key operated lock, or by means of a combination lock or a keypad operated lock. Preferably the locks have different keys, combinations or key codes.

The ammonia tank may be connected to an apparatus for converting ammonia to nitrogen and hydrogen as described in this document. The connection may be via a one-way valve that prevents flow from the cracker to the tank.

According to a ninth aspect of the invention there is provided a method of refilling an ammonia storage tank within a container, the method including the step of adding ammonia to the ammonia storage tank via a filling port that is accessible without opening the container.

In a broader aspect of the invention the eighth and ninth aspects of the invention defined above are modified in that the ammonia storage tank is a storage tank for substances other than ammonia, for example fuels such as propane, and other references to ammonia in respect of the eighth and ninth aspects of the invention are to be construed accordingly.

According to a tenth aspect of the invention there is provided an apparatus for converting ammonia to nitrogen and hydrogen, the apparatus comprising an ammonia storage tank connected to an inlet valve and an outlet valve, access to the inlet valve being controlled by a first lockable housing and access to the outlet valve being controlled by a second lockable housing.

Preferably, the second lockable housing controls access to the ammonia storage tank. Preferably, the second lockable housing controls access to an ammonia cracker. Preferably, the apparatus comprises a fuel cell for generating electricity using hydrogen. Preferably the second lockable housing controls access to the fuel cell. Preferably the first lockable housing comprises a housing, which may be a box or hinged panel, on the outside of the second lockable housing.

When access to a valve is described as being "controlled" it will be understood that the lockable housing, when locked in a closed position, prevents a person on the outside of that housing from touching the valve. For example, the valve may be contained within a box, which can be locked shut.

Preferably the second lockable housing is a freight container. It may be a standard freight container. For example it may be an "8 foot" container or it may be a "10 foot" container. The freight container may have been modified. For example, the first lockable housing may have been added to the container and vents or take-off pipes may pass through the container walls.

When filling an ammonia tank it is important to know how full the tank is. Additionally persons remote from the location of the tank may wish to monitor the refilling of the tank. For example, such persons may wish to know the level of ammonia in the tank or to know when it was last refilled and who refilled it.

According to an eleventh aspect of the invention there is provided an apparatus for converting ammonia to nitrogen and hydrogen comprising an ammonia storage tank within a container, the apparatus comprising measuring means for measuring the level of ammonia within the tank and data transmission means capable of transmitting data from the measuring means to a point outside the container.

The measuring means may be a level transducer. The measuring means may be a load cell. The ammonia storage tank may rest on the load cell. The data transmission means may be wired data transmission means. The data transmission means may be wireless data transmission means.

The data transmission means may be capable of transmitting data to a point immediately outside the container. For example, the data transmission means may be capable of transmitting data to a socket provided on the outside of the container. Such data transmission means are preferably wired, but may be wireless. The socket may be in a secure housing on the outside of the container. For example, the secure housing may be a lockable box.

The data transmission means may be capable of transmitting data to a point remote from the apparatus. For example, the data transmission means may be capable of transmitting data to a control centre in a different country. Such data transmission means are preferably wireless, but may be wired.

A first data transmission means may be capable of transmitting data to a second data transmission means outside the container. For example, there may by a wired data transmission means that is capable of transmitting data to a wireless data transmission means, for example a mobile phone mast, outside the container. The wireless data transmission means may be capable of transmitting the data on to a remote location, for example a control centre in the same or a different country.

The data may be data about the level of ammonia in the tank. However, other data may be transmitted. Examples of other data that may be transmitted include one or more of temperature, pressure, mass, date, time, identity of a refueller, flowrates, concentrations, voltages and currents. For example, data about the level of ammonia in the tank and the mass of the tank may be transmitted to a socket on the outside of the secure enclosure so that a person refilling the tank, who does not have access to the container, can monitor the progress of the refill. Alternatively or additionally, data about the date and time of the refill, the identity of the refiller and the quantity of ammonia added may be transmitted to a control centre in another country.

Other measuring means may be included in the apparatus and connected to the data transmission system. For example, ammonia or hydrogen or other gas detectors or fill status indicators may be included in the apparatus.

The apparatus may comprise a fuel cell. The apparatus may comprise a reactor. The data may comprise data about the operation of the fuel cell or the reactor. For example, the data may comprise one or more of temperature, voltage, current, flow rate or control valve position. Such data may be monitored to understand the state of the apparatus.

Advantageously, the data transmission means are capable of transmitting control signals to the apparatus from a point outside the container. For example, control signals may change the status of control systems or open or close valves. Optionally, the apparatus may comprise more than one reactor and the control signals may start or stop a reactor and shift the load to another reactor. Optionally, the apparatus may comprise more than one fuel cell and the control signals may start or stop a fuel and shift the load to another fuel cell.

The container may be a freight container. The container may be a secure enclosure.

According to a twelfth aspect of the invention there is provided a method of monitoring an apparatus for converting ammonia into nitrogen and hydrogen, contained within a container, the method including the steps of

(a) measuring a parameter inside the container; and

(b) transmitting a measured value of the parameter to a point outside the container.

The container may be a secure container.

The measured value may be transmitted by wired or wireless data transmission means.

The parameter may, for example, be the level of ammonia in a storage tank.

The apparatus may be an apparatus as described elsewhere in this document.

It should be understood that the apparatus and methods of the different aspects of the present invention may be combined in any ways. For example the second and seventh aspects can be combined. Also whilst some features have been described in respect of apparatus according to one aspect of the invention, it is generally the case that the same feature can be employed in an apparatus according to another aspect of the invention or carried out in a method according to one or more aspects of the invention, and similarly a feature described in respect of a method according to one aspect of the invention is generally able to be employed in a method according to another aspect of the invention or may be represented in an apparatus according to one aspect of the invention. Such variations are all to be taken as within the scope of the invention.

In one of its broad aspects the present invention provides an apparatus for converting ammonia gas into nitrogen and hydrogen gases, the apparatus including one or more of any of the following features:

(a) a reactor which includes a first path for containing a catalyst for facilitating conversion of ammonia into nitrogen and hydrogen and in which a downstream end of the path is closed by a gas permeable closure for allowing the passage of gas while obstructing the passage of a solid catalyst;

(b) a first heat exchange arrangement outside a reactor for heating the ammonia before it is passed into the reactor, and a second heat exchange arrangement in the reactor including a second path in the reactor for passing the nitrogen and hydrogen gases through the reactor in heat exchange relationship with the first path to effect further heating of the ammonia;

(c) the apparatus includes a reactor through which the gases pass in use, an induction heating arrangement being provided for heating the gases in the reactor;

(d) the apparatus includes a generally solid body in which a multiplicity of gas passageways are formed;

(e) the apparatus includes a generally solid body comprising a core and a sleeve fitted around the core;

(f) the apparatus includes a reactor including a generally solid body in which in use ammonia is converted into hydrogen and nitrogen, the overall volume of the generally solid body being less than 10,000 cm^3;

(g) the apparatus includes a reactor located within a low pressure chamber;

(h) the apparatus includes a reactor located within an outer storage chamber for storing gases produced in the conversion of ammonia gas into nitrogen and hydrogen gases;

(i) the apparatus includes a fuel cell which is arranged to receive hydrogen generated in use from conversion of ammonia;

(j) the apparatus includes a telecommunications mast forming a transmitter and receiver in a telecommunications system, power for the mast being provided by a fuel cell which is arranged to receive hydrogen generated in use from conversion of the ammonia;

(k) the apparatus includes a reactor and, in use of the apparatus, the highest temperature of the reactor, is less than 200 Celsius above the highest temperature of the gases as they pass through the reactor;

(l) in use of the apparatus, the ammonia is converted into hydrogen and nitrogen in a first process and at least some ammonia remaining from the first process is converted into hydrogen and nitrogen in a second process different from the first process;

(m) the apparatus includes an ammonia storage tank within a container, the ammonia tank being connected to a filling port that is accessible without opening the container;

(n) the apparatus includes an ammonia storage tank connected to an inlet valve and an outlet valve, access to the inlet valve being controlled by a first lockable housing and access to the outlet valve being controlled by a second lockable housing;

(o) the apparatus includes an ammonia storage tank within a container, and includes measuring means for measuring the level of ammonia within the tank and data transmission means capable of transmitting data from the measuring means to a point outside the container.

As will be understood, the features (a) to (o) referred to immediately above may be combined with one another and/or with other features defined elsewhere in this specification with reference to other aspects of the invention.

By way of example, certain embodiments of the invention will now be described with reference to the accompanying drawings, of which:

Figure 1 is a block diagram view of a cracking system,

Figure 2 is a schematic view of an ammonia cracker,

Figure 3 is a sectional view of a reactor, and

Figure 4 is a view of a cracker core forming part of the reactor, and

Figure 5 is a block diagram of a system providing power to a mobile phone mast.

Figure 6 is a schematic view of an ammonia storage system

Figure 7 is a schematic view of an ammonia storage system having more than one storage tank

In Figure 1 an outlet of a drum 10 is shown connected via an isolation valve 12 to a pressure switch 14, which is electrically connected to a heater 16 underneath the drum 10. In some embodiments the pressure switch 14 may be replaced by a temperature gauge. The outlet of the drum downstream of the pressure switch 14 is further connected to a dryer 18, which contains a dessicant, for example that sold under the registered trade mark Sylobead®, and then via a coaxial heat exchanger 20 to a reactor 22. The reactor 22 is heated by a heater 24 and contains a second heat exchanger 26, which will be described below. The outlet from the reactor 22 is connected via the heater exchanger 20 to a tank 28. An outlet from the tank 28 is connected via a microwave secondary cracker 30, via a filter 32, which contains a zeolite, and via a pressure reduction valve 34 to an outlet pipe 36.

Figure 2 shows the layout of an ammonia cracker system 38. The cracker system 38 includes a vessel in which there is the tank 28 surrounding a cylindrical central chamber 40. The central chamber 40 is lined with ceramic microfibre insulation 42 and is partially filled with vermiculite, an insulating material. The central chamber 40 is held at a low pressure of, say, 0.1 bar. Inside the chamber is the reactor 22. The reactor 22 is surrounded by the heater 24 and ceramic fibre insulation 44. The heater 24 is in the form of a coiled heater element and is embedded in the inner surface of the ceramic fibre insulation 44. The central chamber 40 also contains the coaxial heat exchanger 20. The heat exchanger 20 is formed from an inner pipe 46 and an outer pipe 48 coaxial with the inner pipe. Below the central chamber 40 the inner pipe 46 and the outer pipe 48 separate. The outer pipe 48 is connected via an isolation valve 52 and a pipe 54 to the tank 28. An inlet pipe 53 is connected via a non-return valve 50 to the inner pipe 46. At the top of the tank 28 there is a further isolation valve 56 via which an outlet to the tank 28 is connected to the filter 32, which is further connected to a fine filter 58. The filter 32 contains a zeolite. Downstream of the fine filter 58 is the pressure reduction valve 34, which in turn is connected to the outlet pipe 36.

The reactor 22 is shown in more detail in Figure 3. The centre of the reactor 22 contains the inner coaxial pipe 46 and outer coaxial pipe 48. The outer pipe 48 has holes 60 in its walls in the region of an end of the pipe. That end of the pipe is supported on a hollow frustoconical support 62. Surrounding the pipes is a core 64 made from a suitable corrosion resistant material, for example Inconel®. The core 64 contains eight grooves 66 and eight return grooves 68 in its outer surface. The grooves 66 and return grooves 68 alternate around the circumference of the core 64. For convenience a groove 66 is shown at the top of Figure 3 and a return groove 68 is shown at the bottom. The grooves 66 open into a chamber 70 at one end but are closed by a stop 72 at the other. The return grooves 68 are closed by the stop 72 at one end and at the other have a hole 74 which extends radially into the core 64. That hole 74 is connected to a first end of a respective one of eight catalyst chambers 76. The second end of the catalyst chamber 76 is capped by a gas-permeable thimble 78. The core 64 is surrounded by an outer shell 80, which fits tightly around the core 64 so that gas-tight seals 82 and 84 are formed with the grooves 66 and the return grooves 68 defining channels in the reactor.

Figure 4 shows a perspective view of the core 64. The grooves 66 and return grooves 68 are around the outside and the stop 72 is at the top. At the bottom of the return grooves 68 are the holes 74 which connect with the catalyst chambers 76. The catalyst chambers 76 have openings at the top of the core 64, two of which are shown in Figure 4 with gas-permeable thimbles 78 in them, although it should be understood that such thimbles 78 are provided at the tops of all the chambers 76.

In use of the apparatus described herein with reference to Figures 2 to 4, ammonia enters the cracker through the pipe 53 and passes through the non-return valve 50. In this particular example, the ammonia enters at a pressure of about 6 bar and a temperature of about 20 Celsius. The ammonia then enters the pipe 46. The gases in pipe 46 are separate from the gases in pipe 48, but heat can transfer between the gases through the wall of pipe 46. The ammonia passes along pipe 46, through the coaxial heat exchanger 20, where the temperature of the ammonia is increased in this particular example to about 400 Celsius due to heat transfer from the hot gases in pipe 48. Of course, heat transfer takes place throughout the length where pipe 46 runs coaxially inside pipe 48. However, coaxial heat exchanger 20 increases the length of coaxial pipe over which that transfer takes place.

The ammonia then enters the reactor 22 through the inner coaxial pipe 46 and passes into the chamber 70. The ammonia then flows along the grooves 66 in the outside of the core. On reaching the stop 72 at the end of each groove 66, the gas flows around a circumferentially interconnecting groove until it reaches the entrance to a return groove 68. As it flows along the grooves 66 and return grooves 68 it is heated to a cracking temperature of about 700 Celsius. The heating is due to heat transfer from the core 64 and the outer shell 80, which are heated by the heater 24.

After flowing along each return groove 68 the ammonia flows through hole 74 and into a respective one of the catalyst chambers 76, which are filled with beads of catalyst. As the ammonia passes through each catalyst chamber 76 it is cracked to form hydrogen and nitrogen in the ratio of three hydrogen molecules to one nitrogen molecule. Every two moles of ammonia that are cracked produce one mole of nitrogen and three moles of hydrogen. Ammonia is converted in the catalyst chambers 76. The majority of the cracking takes place in a small portion of each catalyst chamber 76 and as the catalyst ages the cracking will take place in different portions of the chamber 76. Since the cracking is an endothermic reaction heat transfer must take place from the core 64 into the gases in each catalyst chamber 76 to maintain them at the cracking temperature. The temperature of the core 64 must be such that sufficient heat transfer occurs to maintain the gases at the cracking temperature at the point of greatest reaction rate. As a result, in portions of each catalyst chamber 76 where the reaction rate is lower than the maximum, the gases are hotter than the cracking temperature. In particular, towards the exit of each catalyst chamber 76 there is a low concentration of ammonia and the reaction rate is therefore lower than toward the entrance of the catalyst chamber 76. Thus the gases exiting each catalyst chamber 76 through the gas permeable thimble 78 are hotter than the initial cracking temperature.

The hot gases exiting the catalyst chamber 76 through the gas-permeable thimble 78 then flow past the inside surface of the core 64, transferring heat to the core as they do so, and enter the outer coaxial pipe 48 through holes 60. The hot gases then flow along outer coaxial pipe 48 and heat is transferred to the incoming ammonia in inner coaxial pipe 46. Thus energy from the excess heating in the catalyst chamber 76 is transferred to the incoming ammonia stream. The product gas stream therefore exits the reactor 22 at a temperature below the cracking temperature of 700 Celsius.

Thus it can be seen that in the reactor 22 shown in the drawings, a multiplicity of gas passages are found in the body of the reactor, the passages extending between first and second end regions of the reactor.

On leaving the reactor 22, the hot product gases, which include nitrogen, hydrogen and ammonia pass along the outer coaxial pipe 48, through the coaxial heat exchanger 20, where some of the heat in the gases is transferred to the ammonia stream in the inner coaxial pipe 46, and on to isolation valve 52. At valve 52, the gases may be vented to atmosphere, or to another suitable location, or may be directed along pipe 54 and into the tank 28. Tank 28 will contain hydrogen and nitrogen and any ammonia that has not been cracked in the reactor 22. The pressure of the gases stored in the tank 28 is about 6 bar.

Gas is removed from the tank 28 via the isolator valve 56, after which it passes through the filter 32 and the fine filter 58. In this particular example, the filter 32 and the fine filter 58 remove some of the ammonia that is present in the gases leaving the tank 28.

The gas also passes through pressure reduction valve 34 before being available for further use via pipe 36. In this example, the pressure reduction valve 34 reduces the pressure from about 6 bar to about 1 bar.

As will be understood the ammonia cracker described here with reference to Figures 2 to 4 is incorporated with only slight modification in the system shown in Figure 1. The system of Figure 1 includes a heater and a dryer and various other components upstream of the coaxial heat exchanger 20 (and the non-return valve 50). Also the arrangement shown downstream of the tank 28 is different in Figures 1 and 2. As will be understood, different arrangements may be used in different applications. For example in the system of Figure 1 a second cracker 30 is provided to remove at least some of the small remaining amount of ammonia in the gases leaving the reactor 22, whereas in Figure 2 an extra filter is provided.

In a particular example of the invention, the cracker is designed to crack 2 m^3 per hour of ammonia, producing 3 m^3 per hour of hydrogen and 1 m^3 per hour nitrogen, all at STP.

The tank 28 is able to store 200 litres of hydrogen and nitrogen at a pressure of 6 bar. The reactor 22 has a length of 200 mm and a diameter of 90 mm, with each of the catalyst chambers 76 having a length of 150 mm and a diameter of 15 mm. The catalyst chambers 76 together contain a total of 100 g of catalyst (Sud Chemie G90).

In use, the ammonia is, in this particular example, heated to a temperature of about 700 Celsius before cracking.

The cracker's peak power consumption is of the order of 950 W and it provides enough ammonia to supply a hydrogen fuel cell system with a power output of about 5 kW, based on current commercially available fuel cells. Such a fuel cell system is suitable, for example, for powering a mast with a mobile telephone transmitter and receiver of the kind used in standard mobile telecommunications systems. In Figure 5 a standard freight or shipping container of length about 2.4 m (commonly referred to as an "8ft" container) 102 contains six ammonia tanks 104, which are connected to the inlet of an ammonia cracker 38, the outlet of which is connected to a hydrogen fuel cell 106. A mobile phone mast 100 is electrically connected to, and powered by, the hydrogen fuel cell 106.

In Figure 6 a 440 kg ammonia tank 200 is situated within a secure container or enclosure 201. The ammonia tank 200 is supported on a load cell 202, which is connected via a data connection line 203 to an electrical data socket 204. The electrical data socket 204 is also connected to a fill level transducer 205 in the ammonia tank 200 by data connection line 206. The electrical data socket 204 is contained in a box 207 on the side of the secure container or enclosure 201. The box 207 has a hinge 208 at the top and a lock 209, which may for example be a padlock, at the bottom. The box 207 also contains a dry-coupling fill port 210. The dry-coupling fill port 210 is connected by an inlet pipe 211 to the ammonia tank 200, via a one-way valve 212. The ammonia tank 200 is also connected, via a one-way valve 213, to an outlet pipe 214 that connects to an ammonia cracker (not shown in Fig. 6). A pressure relief valve 215 is connected to the ammonia tank 200 and there is a liquid ammonia off-take pipe 216 with a manual shut-off valve 217 connected to the bottom of the ammonia tank 200. The manual shut-off valve 217 is situated within the secure container or enclosure 201. There is a manual shut-off valve 219 on the inlet pipe 211 and a manual shut-off valve 218 on the outlet pipe 214. In the tank 200 there is a float valve 220 that prevents the tank 200 being filled to a level of more than 85% of the volume of the tank 200.

To refill the ammonia tank 200, the box 207 is opened, by unlocking the lock 209 and rotating the box about the hinge 208, and an ammonia supply (not shown in Fig. 6) is connected to the dry-coupling fill port 210. An appropriate data reader is attached to the electrical data connection 204. The mass of the ammonia tank 200 is measured by the load cell 202 and the level in the tank 200 is measured by the fill level transducer 205 and the information fed to the data reader via the electrical data connection 204. Ammonia is then added to the tank 200 via the dry-coupling fill port 210. The one-way valve 212 prevents back-flow of ammonia. When the tank 200 is filled to the desired level, the ammonia supply and data reader are disconnected from the dry-coupling fill port 210 and the electrical data connection 204, and the box 207 is closed and the lock 209 locked.

With the box 207 locked shut the ammonia tank 200 is thus contained within the secure container or enclosure 201. Ammonia cannot be removed from the tank 200 via the dry-coupling fill port 210 because it is inside the box 207, which is locked, and, in any case, because the one-way valve 212 prevents this. Ammonia can also not be removed via the off-take pipe 216 because the manual shut-off valve 217 is closed and is contained within the secure enclosure or container 201. Thus the ammonia in the tank 200 is securely stored for use in supplying an ammonia cracker via pipe 214. One-way valve 213 prevents back-flow from the cracker to the tank 200. Excess pressure will be released via pressure relief valve 215.

If the tank 200 needs to be emptied for maintenance purposes, secure container or enclosure 201 is opened and the ammonia is drained via off-take pipe 216 by opening manual shut-off valve 217. The tank 200 can be isolated by closing manual shut-off valves 217, 218 and 219. That may be necessary if the tank needs to be removed for maintenance.

The system in Figure 6 may therefore provide three different levels of access. When the secure container or enclosure 201 is closed and the box 207 locked the ammonia tank 200 is inaccessible. A person who is provided with a key to the lock 209 can access the dry-coupling fill port 210 and the electrical data connection 204 and can thus refill the ammonia tank 200, but cannot remove any ammonia from it. A person who is provided with a key to the lock 209 and means for accessing the secure container or enclosure 201 can access the dry-coupling fill port 210, the electrical data connection 204 and the manual shut-off valve 217 and can thus both fill and empty the tank 200. In use, the secure container or enclosure 201 and the lock 209 would normally be locked so that unauthorised removal of ammonia would be prevented. A contractor or other person employed or authorised to refill the tank 200 would be given a key to the lock 209 so that they could perform that task. Means for accessing the secure container or enclosure 201 would be reserved for those people who were authorised to carry out maintenance on the system.

In Figure 7 there are two ammonia tanks 300 and 301. Each of those tanks is connected, via a one-way valve 302 and 303 to a filling pipe 304. The tanks 300 and 301 are also connected, via electrically controlled flow valves 305 and 306, to an ammonia supply pipe 307, which is connected to an ammonia cracker (not shown in Fig. 7). The tanks 300 and 301 are also connected to an ammonia off-take pipe 308 via manual shut-off valves 309 and 310. The tanks 300 and 301 may be isolated by closing manual shut-off valves 309, 310, 311, 312, 313 and 314. That may be necessary if either of the tanks 300 or 301 needs removing for maintenance.

It will be appreciated that the tanks 300 and 301 may be incorporated in a system similar to that shown in Figure 6. For example, the tanks 300 and 301 may both be inside a single, common secure container and rest on load cells and the filling pipe 304 may be connected to a dry-coupling fill port in a lockable box on the secure container.

Inevitably the cracker shown in Figs. 2 to 4 takes a period of time to warm up. In a case where such a time lag is not acceptable, an option is to provide a second cracker of a different kind that can run as a substitute for the cracker shown in Figs. 2 to 4. In particular a cracker relying on high frequency wave energy, such as microwaves, to provide the energy required for cracking may be provided. Even if such a second cracker is less efficient, that may not be significant if it is run as a substitute for the first cracker for only short periods of time. When the second cracker is not required as a substitute for the first it may be connected in series with the first cracker in order to convert any relatively small amounts of ammonia remaining in the gases after their passage through the first cracker. The use of such a second cracker in this way can reduce the need to filter the gases before they are passed to a fuel cell. The second cracker can readily be fitted into the container 102 along with the other equipment.

In the particular example described, the ammonia is heated to a temperature of about 700 Celsius. That is a relatively low temperature for cracking and may be appropriate especially if there is a second cracker or if a relatively large amount of ammonia in the gas products can be tolerated. If desired, the ammonia may be heated to a higher temperature, for example about 800 or about 850 Celsius, thereby reducing the amount of ammonia in the gas products. That may be appropriate especially if there is not a second cracker.

Hydrogen fuel cells are able to run on a mixture of hydrogen and nitrogen and therefore, when the cracker is being used to supply such a fuel cell, it may not be necessary to separate the hydrogen and nitrogen. Of course, if that is preferable it can readily be done adopting methods that are well known *per se*.

Claims:

1. An apparatus for converting ammonia gas into nitrogen and hydrogen gases, the apparatus including:

(a) a heater for heating ammonia to convert it into gas;

(b) a reactor including a first path for containing a catalyst for facilitating conversion of ammonia into nitrogen and hydrogen;

(c) a first heat exchange arrangement outside the reactor for heating the ammonia before it is passed into the reactor, and

(d) a second heat exchange arrangement in the reactor including a second path in the reactor for passing the nitrogen and hydrogen gases through the reactor in heat exchange relationship with the first path to effect further heating of the ammonia.

2. An apparatus according to claim 1, in which the first heat exchange arrangement comprises a pipe-in-pipe arrangement, one of the pipes being for passing ammonia into the vessel and the other of the pipes being for receiving the nitrogen and hydrogen gases from the reactor.

3. An apparatus according to claim 2, in which the pipe in pipe arrangement follows a tortuous path.

4. An apparatus according to any preceding claim, in which the second heat exchange arrangement is formed by a generally solid body of thermally conducting material within which the first and second paths are provided, the thermally conducting solid body providing a path for heat to be exchanged between the second path and the first path.

5. An apparatus according to any preceding claim, including a heater for heating the generally solid body of thermally conducting material.

6. An apparatus according to claim 5, in which the heater is an induction heater.

7. An apparatus according to any of claims 4 to 6, in which a multiplicity of passageways are formed in the

generally solid body, the passageways including one or more sets of passageways extending between a first end region of the solid body and a second end region of the solid body opposite the first end region, the passageways in the or each set of passageways being approximately parallel to one another, connected in series with one another, and defining the first and second paths.

8. An apparatus according to claim 7, in which there are a plurality of sets of passageways.

9. An apparatus according to claim 7 or 8, in which the or each set of passageways includes an elongate chamber for containing catalyst.

10. An apparatus according to claim 9, in which a downstream end of the chamber for containing catalyst is closed by a gas permeable closure for allowing the passage of gas while obstructing the passage of a solid catalyst.

11. An apparatus according to claim 9 or 10, in which the or each set of passageways include one or more upstream passageways connected upstream of the elongate chamber.

12. An apparatus according to claim 11, in which the or each set of passageways includes a first upstream passageway extending from the first end region of the generally solid body to the second end region and a second upstream passageway connected in series with the first upstream passageway and extending from the second end region of the solid body to the first end region.

13. An apparatus according to any of claims 9 to 12, in which the or each set of passageways include a downstream passageway connected downstream of the elongate chamber.

14. An apparatus according to any of claims 7 to 13, in which the generally solid body comprises a core and a sleeve fitted around the core, some of the passageways being defined by channels formed between the periphery of the core and the sleeve.

15. An apparatus according to claim 14, in which the channels formed between the periphery of the core and the sleeve include at least one pair of channels which are

connected to one another at the first end region of the generally solid body.

16. An apparatus according to claim 15 when dependent upon claim 12, in which the pair of channels define the first and second upstream passageways.

17. An apparatus according to any of claims 7 to 16, in which the plurality of sets of passageways are angularly spaced around the longitudinal axis of the generally solid body.

18. An apparatus according to any of claims 7 to 17, in which the generally solid body is elongate and of approximately circular cross-section.

19. An apparatus according to any of claims 7 to 18, in which the generally solid body has a central portion extending from the first end region to the second end region, the central portion defining an inlet pipe for conveying ammonia to the one or more sets of passageways and an outlet pipe for conveying nitrogen and hydrogen gases out of the reactor.

20. An apparatus according to claim 19, in which the inlet pipe enters the generally solid body in the first end region extends through the central portion of the body and opens into a chamber in the second end region of the solid body.

21. An apparatus according to claim 20, in which the chamber extends radially outwardly beyond the central portion of the end region of the body.

22. An apparatus according to any of claims 19 to 21, in which the outlet pipe extends through the central region of the body around the inlet pipe and leaves the generally solid body in the first end region of the generally solid body.

23. An apparatus according to any of claims 4 to 22, in which the overall volume of the generally solid body is less than 10,000 cm^3.

24. An apparatus according to any preceding claim, in which the reactor is housed in a chamber within a larger vessel.

25. An apparatus according to claim 24, in which the vessel includes an outer storage chamber for storing gases produced in the conversion of the ammonia, the chamber housing the reactor being disposed within the outer storage chamber.

26. An apparatus according to claim 24 or 25, in which the chamber housing the reactor is a low pressure chamber

27. An apparatus according to any of claims 24 to 26, in which the top of the inside of the chamber housing the reactor is spaced from the top of the reactor.

28. An apparatus according to any of claims 24 to 27, in which the first heat exchange arrangement is disposed inside the vessel.

29. An apparatus according to any of claims 24 to 28, in which the interior volume of the vessel is less than 1 m^3.

30. An apparatus for converting ammonia gas into nitrogen and hydrogen gases, the apparatus being substantially as herein described with reference to the accompanying drawings.

31. An electricity generating system including a hydrogen fuel cell for generating electricity from hydrogen and an apparatus according to any preceding claim for generating hydrogen.

32. A system according to claim 31, in which the entire system can be fitted inside a standard freight container having a length of about 3 metres.

33. A system according to claim 31 or 32, suitable for providing power to a telecommunications mast.

34. A method of converting liquid ammonia into nitrogen and hydrogen gases, the method including the following steps:

(a) heating the liquid ammonia to convert it into gas;

(b) passing the ammonia gas along a first path through a reactor containing a catalyst, causing conversion of the ammonia gas into nitrogen and hydrogen gases, and

(c) passing the nitrogen and hydrogen gases generated in the reactor through a heat exchange arrangement to effect heating of the ammonia before it is passed through the reactor,

wherein the method further includes the step of

(d) passing the nitrogen and hydrogen gases along a second path through the reactor vessel in heat exchange relationship with the first path to effect further heating of the ammonia.

35. A method according to claim 34, in which the ammonia gas is heated as it passes along the first path.

36. A method according to claim 35, in which at least some of the heating is provided by radiant heating.

37. A method according to claim 35, in which at least some of the heating is provided by induction heating.

38. A method according to claim 37, in which the highest temperature of the reactor, including any heater associated with the vessel for heating the gases, is less than 200 Celsius above the highest temperature of the gases as they pass through the reactor.

39. A method according to any of claims 34 to 38, in which the method is carried out using an apparatus according to any of claim 1 to 30.

40. A method of converting liquid ammonia into nitrogen and hydrogen gas, the method including the following steps:

(a) converting the ammonia into nitrogen and hydrogen gases by means of a first process;

(b) preparing to operate a second process for converting the ammonia, while the first process is operating, the second process being a method according to any of claims 34 to 39; and, subsequently,

(c) converting the ammonia into nitrogen and hydrogen gases by means of the second process.

41. A method according to claim 40, including the step of stopping the conversion of ammonia by means of the first

process and a subsequent step of stopping the conversion of ammonia by the second process

42. A method according to claim 41, in which the first process continues to operate after the second process has started, with at least some products of the second process being subsequently subjected to the first process.

43. A method according to claim 42, in which the products of the second process comprise nitrogen, hydrogen and ammonia gases and at least the ammonia gas from the second process is subjected to the first process.

44. A method according to any of claims 40 to 43, in which the first process includes exposing the ammonia to microwaves.

45. A method of converting liquid ammonia into nitrogen and hydrogen gases, the method being substantially as herein described with reference to the accompanying drawings.

46. An apparatus for converting ammonia gas into nitrogen and hydrogen gases, the apparatus including a generally solid body of thermally conducting material within which a multiplicity of passageways are formed, the passageways including one or more sets of passageways extending between a first end region of the solid body and a second end region of the solid body opposite the first end region, the passageways in the or each set of passageways being approximately parallel to one another, connected in series with one another, and including at least one passageway for containing a catalyst for catalysing the conversion of ammonia gas into nitrogen and hydrogen gases.

47. An apparatus for converting ammonia gas into nitrogen and hydrogen gases, the apparatus including a vessel including an outer storage chamber for storing gases produced in the conversion and an inner chamber containing a reactor for converting ammonia gas into nitrogen and hydrogen gases.

48. An apparatus for converting ammonia gas into nitrogen and hydrogen gases, the apparatus including a vessel

including a reactor for converting ammonia gas into nitrogen and hydrogen gases, the reactor being located within a low pressure chamber contained within the vessel.

49. A method of converting liquid ammonia into nitrogen and hydrogen gas, the method including the following steps:

(a) heating the liquid ammonia to convert it into gas;

(b) passing the ammonia gas along a path through a reactor containing a catalyst, causing conversion of the ammonia gas into nitrogen and hydrogen gases, and

(c) heating the gases as they pass along the first path through the reactor,

wherein the highest temperature of the reactor, including any heater associated with the reactor for heating the gases, is less than 200 Celsius above the highest temperature of the gases as they pass through the reactor.

50. A method of converting liquid ammonia into nitrogen and hydrogen gas, the method including the following steps:

(a) heating the liquid ammonia to convert it into gas;

(b) passing the ammonia gas along a path through a reactor containing a catalyst, causing conversion of the ammonia gas into nitrogen and hydrogen gases, and

(c) heating the gases as they pass along the first path through the reactor,

wherein at least some of the heating carried out on the gases as they pass along the first path through the reactor is induction heating.

51. A method of converting liquid ammonia into nitrogen and hydrogen gas, the method including the following steps:

(a) converting the ammonia into nitrogen and hydrogen gases by means of a first process;

(b) preparing to operate a second process for converting the ammonia, while the first process is operating; and, subsequently,

(c) converting the ammonia into nitrogen and hydrogen gases by means of the second process.

52. A method according to claim 51, in which the first process continues to operate after the second process has started, with products of one of the first and second processes being subsequently subjected to the other of the first and second processes.

53. A method according to any of claims 50 to 52, in which the second process includes passing the ammonia gas along a path through a reactor containing a catalyst.

54. A method according to any of claims 50 to 53, in which the first process includes exposing the ammonia to high frequency wave energy of frequency greater than 100MHz.

55. An apparatus for storing liquid ammonia, the apparatus comprising an ammonia storage tank within a container, the ammonia tank being connected to a filling port that is accessible without opening the container.

56. An apparatus according to claim 55, wherein the ammonia tank is connected to a take-off pipe comprising a valve, the valve being inaccessible when the container is closed.

57. An apparatus according to claim 55 or 56, wherein the apparatus comprises means for measuring the amount of ammonia in the tank.

58. An apparatus according to claim 57, wherein the measuring means is connected to a data port, which is accessible without opening the container.

59. An apparatus according to any of claims 55 to 58, wherein the filling port is in a lockable housing on the outside of the container.

60. An apparatus according to claim 59, wherein the data port is in the lockable housing.

61. An apparatus for converting ammonia to nitrogen and hydrogen, the apparatus comprising an ammonia storage tank connected to an inlet valve and an outlet valve, access to the inlet valve being controlled by a first lockable

housing and access to the outlet valve being controlled by a second lockable housing.

62. An apparatus according to claim 61, wherein the second lockable housing controls access to the ammonia storage tank.

63. An apparatus for converting ammonia to nitrogen and hydrogen comprising an ammonia storage tank within a container, the apparatus comprising measuring means for measuring the level of ammonia within the tank and data transmission means capable of transmitting data from the measuring means to a point outside the container.

64. An apparatus according to claim 63, wherein the data transmission means is wired data transmission means.

65. An apparatus according to claim 63, wherein the data transmission means is wireless data transmission means.

66. A method of monitoring an apparatus for converting ammonia into nitrogen and hydrogen, contained within a container, the method including the steps of

(a) measuring a parameter inside the container; and

(b) transmitting a measured value of the parameter to a point outside the container.

67. A method according to claim 66, wherein, the measured value is transmitted by wired data transmission means.

68. A method according to claim 66, wherein, the measured value is transmitted by wireless data transmission means.

69. A method according to claim 68, wherein the parameter is the level of ammonia in a storage tank.

70. An apparatus for converting ammonia gas into nitrogen and hydrogen gases, the apparatus including one or more of any of the following features:

(a) a reactor which includes a first path for containing a catalyst for facilitating conversion of ammonia into nitrogen and hydrogen and in which a downstream end of the path is closed by a gas permeable closure for allowing the passage of gas while obstructing the passage of a solid catalyst;

(b) a first heat exchange arrangement outside a reactor for heating the ammonia before it is passed into the reactor, and a second heat exchange arrangement in the reactor including a second path in the reactor for passing the nitrogen and hydrogen gases through the reactor in heat exchange relationship with the first path to effect further heating of the ammonia;

(c) the apparatus includes a reactor through which the gases pass in use, an induction heating arrangement being provided for heating the gases in the reactor;

(d) the apparatus includes a generally solid body in which a multiplicity of gas passageways are formed;

(e) the apparatus includes a generally solid body comprising a core and a sleeve fitted around the core;

(f) the apparatus includes a reactor including a generally solid body in which in use ammonia is converted into hydrogen and nitrogen, the overall volume of the generally solid body being less than 10,000 cm^3;

(g) the apparatus includes a reactor located within a low pressure chamber;

(h) the apparatus includes a reactor located within an outer storage chamber for storing gases produced in the conversion of ammonia gas into nitrogen and hydrogen gases;

(i) the apparatus includes a fuel cell which is arranged to receive hydrogen generated in use from conversion of ammonia;

(j) the apparatus includes a telecommunications mast forming a transmitter and receiver in a telecommunications system, power for the mast being provided by a fuel cell which is arranged to receive hydrogen generated in use from conversion of the ammonia;

(k) the apparatus includes a reactor and, in use of the apparatus, the highest temperature of the reactor, is less than 200 Celsius above the highest temperature of the gases as they pass through the reactor;

(l) in use of the apparatus, the ammonia is converted into hydrogen and nitrogen in a first process and at least some ammonia remaining from the first process is converted into hydrogen and nitrogen in a second process different from the first process;

(m) the apparatus includes an ammonia storage tank within a container, the ammonia tank being connected to a filling port that is accessible without opening the container;

(n) the apparatus includes an ammonia storage tank connected to an inlet valve and an outlet valve, access to the inlet valve being controlled by a first lockable housing and access to the outlet valve being controlled by a second lockable housing;

(o) the apparatus includes an ammonia storage tank within a container, and includes measuring means for measuring the level of ammonia within the tank and data transmission means capable of transmitting data from the measuring means to a point outside the container.

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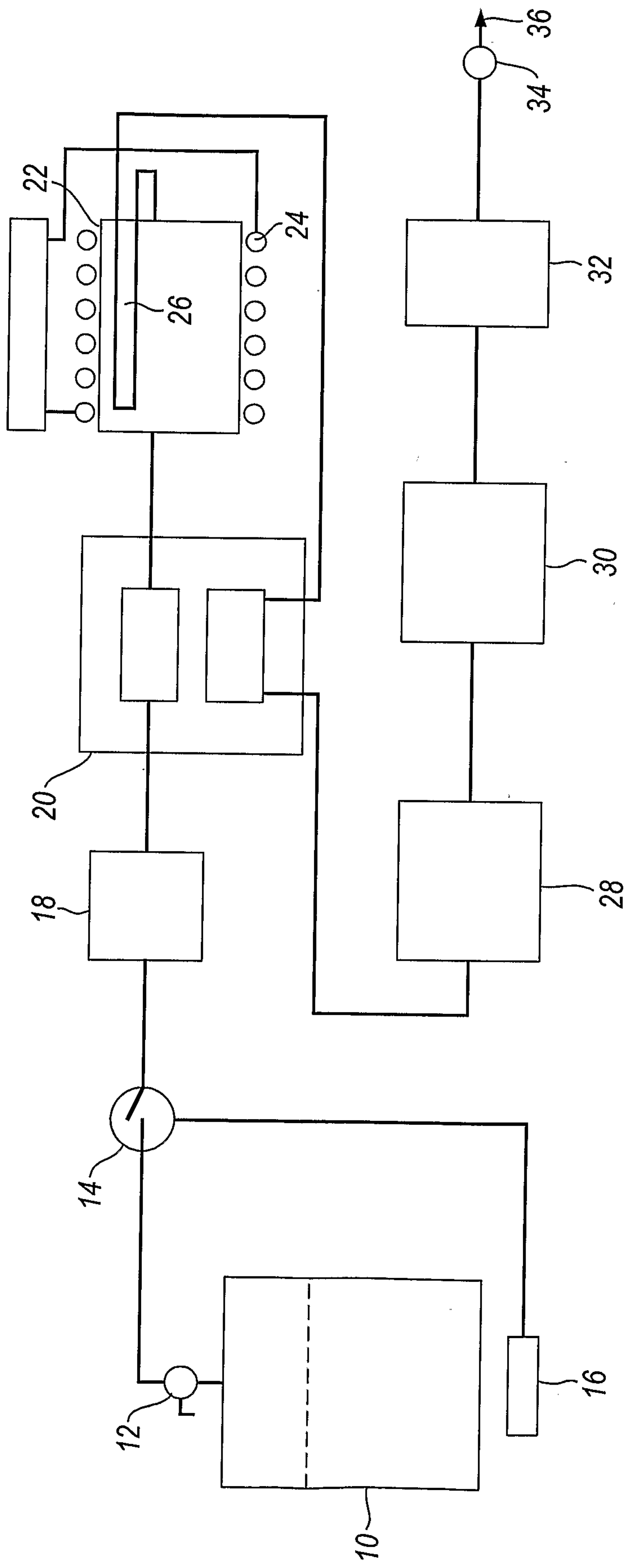

Fig.1

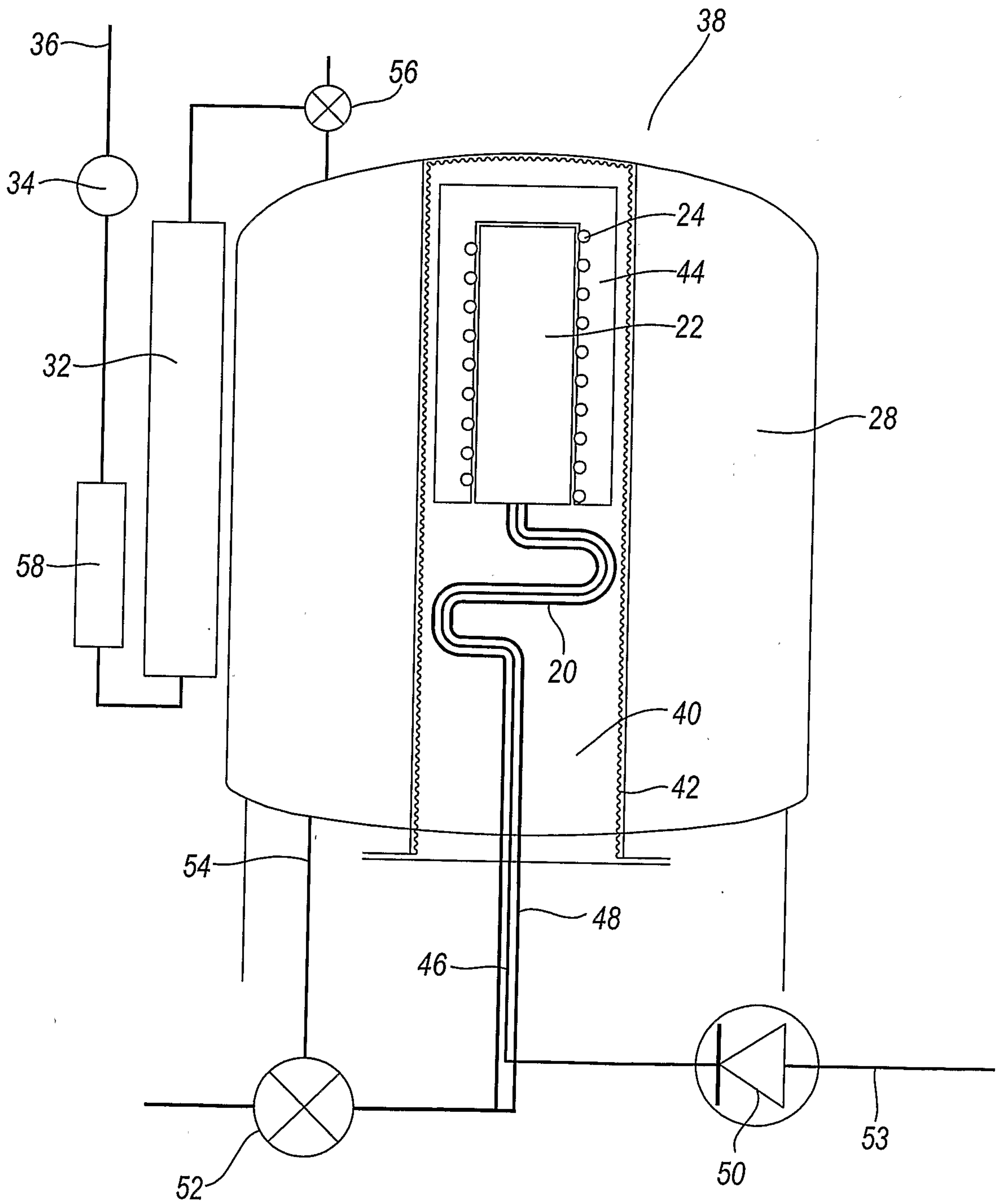

Fig.2

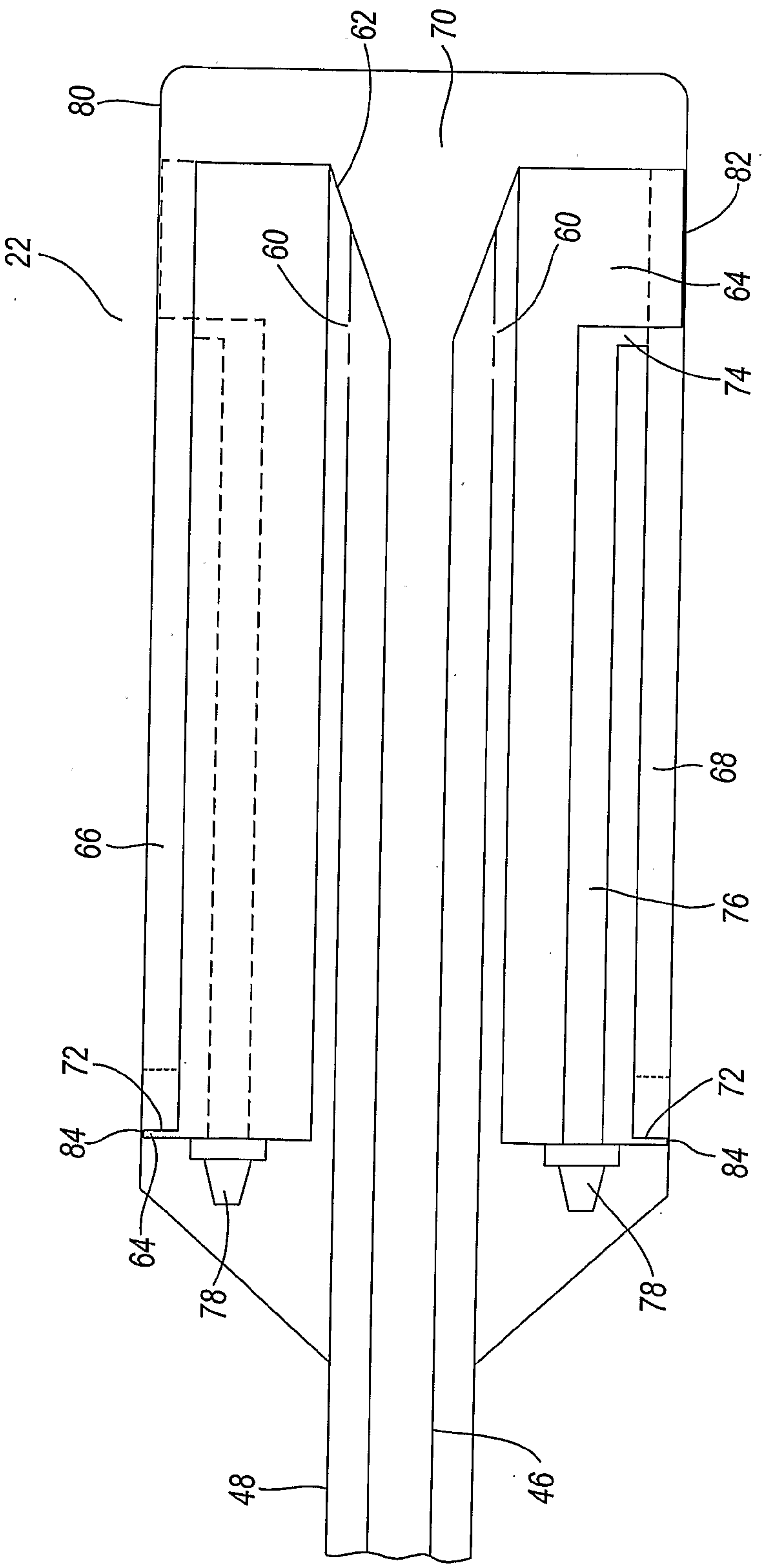

Fig.3

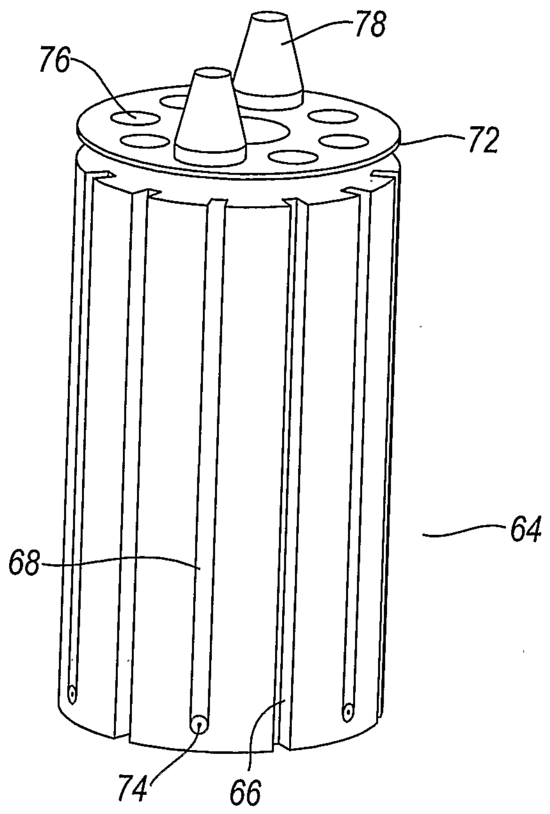

Fig.4

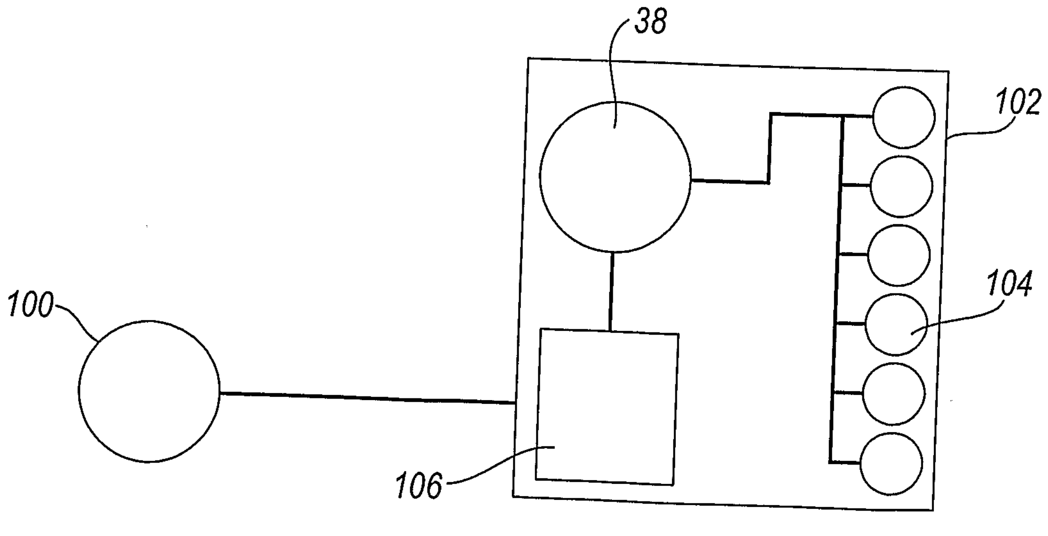

Fig.5

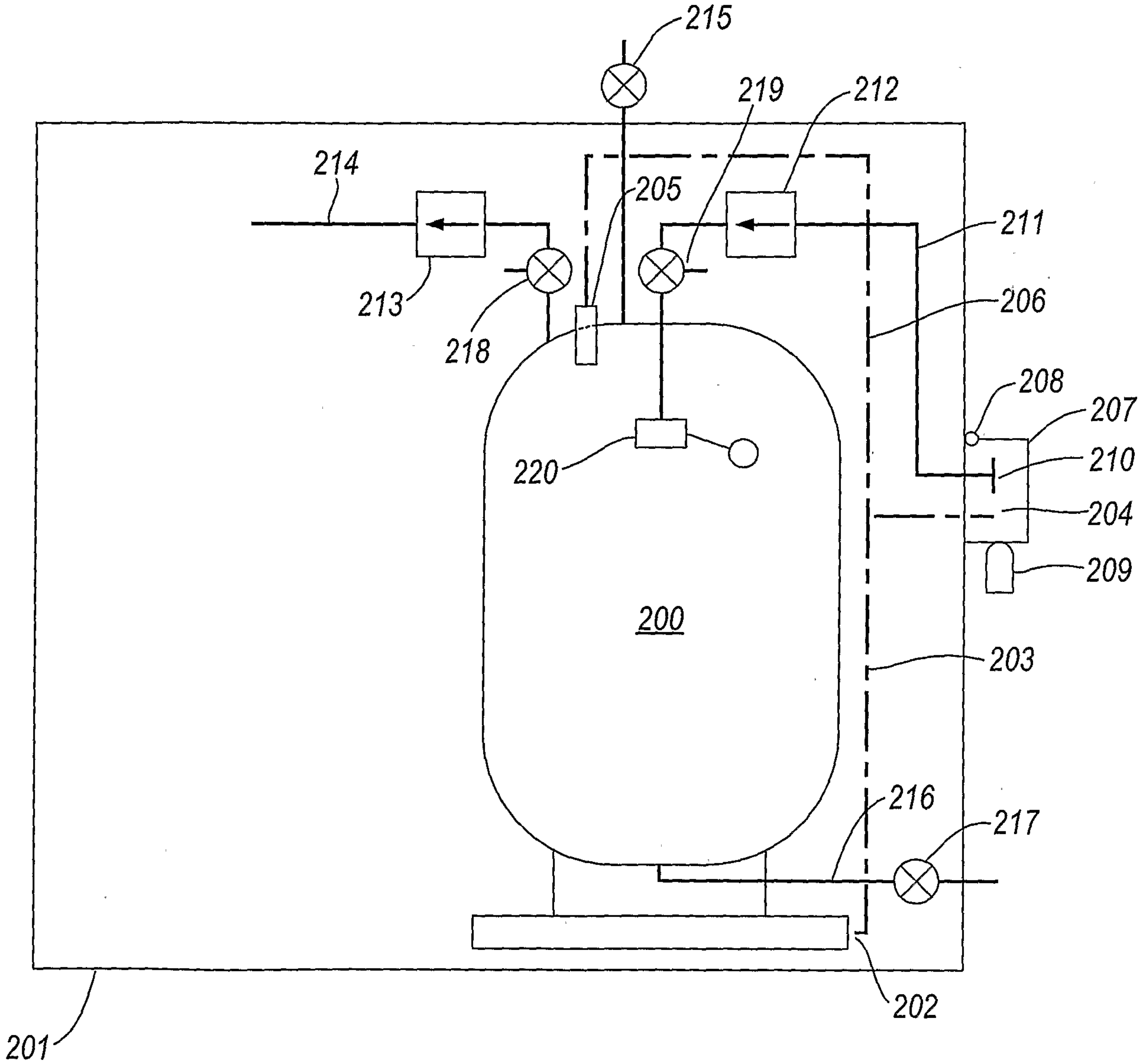
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Fig.6

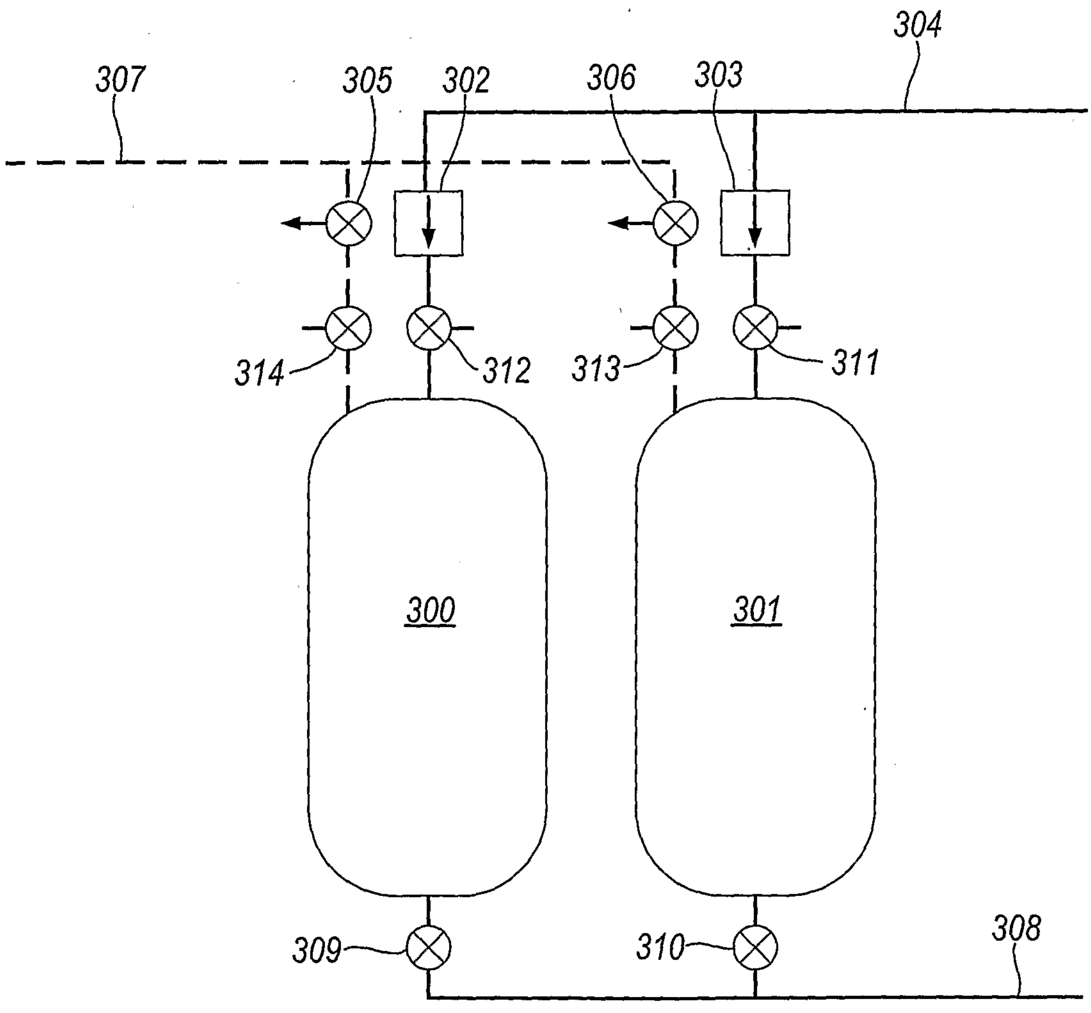

Fig.7