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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
21 February 2008 (21.02.2008)

PCT

(10) International Publication Number
WO 2008/020194 A1

(51) International Patent Classification:
F01N 3/20 (2006.01) *B01D 53/86* (2006.01)
F01N 3/28 (2006.01) *B01D 53/94* (2006.01)
F01N 5/02 (2006.01)

(21) International Application Number: PCT/GB2007/003093

(22) International Filing Date: 14 August 2007 (14.08.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0616150.9 15 August 2006 (15.08.2006) GB

(71) Applicant *(for all designated States except US)*: **IMI VISION LIMITED** [GB/GB]; Tything Road, Alcester, Warwickshire B49 6EU (GB).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **BARBER, Graham, Richard** [GB/GB]; 52 Braemar Road, Sutton Coldfield, West Midlands B73 6LS (GB). **DAVEY, Stuart, Charles** [GB/GB]; 48 Flying Fields Road, Southam, Warwickshire CV47 1GA (GB). **COATES, James** [GB/GB]; 11 Station Road, Tilbrook, Huntingdon, Cambridgeshire PE28 0JT (GB). **SEALY, Mark** [GB/GB]; 2 Jacksons Meadow, Bidford Upon Avon, Warwickshire B50 4HQ (GB).

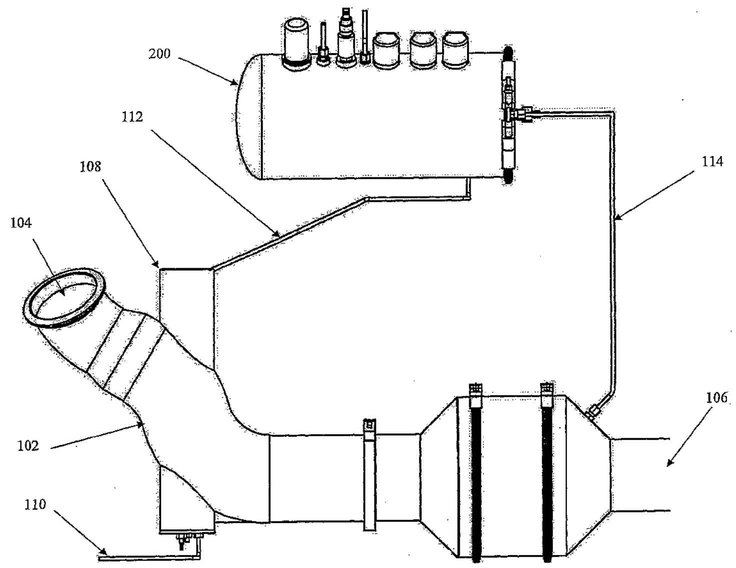
(74) Agent: **WIGHTMAN, David, A.**; Barker Brettell, 138 Hagley Road, Edgbaston, Birmingham, B16 9PW (GB).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, 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, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, 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, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

(54) Title: EXHAUST GAS TREATMENT



(57) Abstract: Apparatus for reducing NOx in the exhaust gasses of a vehicle has a housing (102) connectable inline in the exhaust system and provided with a reaction vessel within a vertical section (108). The reaction vessel has an inlet (110) for the supply of aqueous urea and an outlet (112) for removal of gaseous hydrolysis product. The outlet (112) is connected to a reservoir (200) which provides the NOx containing exhaust gas with the required amount of hydrolysis gas via a conduit (114) to pass therewith through an SCR catalyst to reduce the NOx content. The reservoir (200) includes a temperature sensor (210) to monitor the temperature within the reservoir (200) and a heating element (208) operable to heat the reservoir (200) in response to the temperature sensed by the temperature sensor being below a predetermined temperature.

WO 2008/020194 A1

Exhaust Gas Treatment

The present invention relates to an apparatus for reducing emissions of Nitrogen oxides (NOx) in exhaust gasses of an internal combustion (IC) engine.

The introduction of reagents into the flow of an exhaust gas of an IC engine prior to the gas passing through a catalyst in order to effect Selective Catalytic Reduction (SCR) of NOx is well known.

Some of the known systems take an aqueous solution of urea and decompose it in a reactor to produce an ammonia-containing gas which is then added to the exhaust gas as a reagent.

Such a system has been proposed in United States Patent 6,361,754 and comprises hydrolysing aqueous urea under pressure at a high temperature so that it decomposes into at least gaseous ammonia and then introducing the gaseous ammonia into the exhaust conduit. While this is an efficient method of preparing ammonia gas in situ, as the heating is dependant on the reactor being placed in the exhaust conduit and the pressure under which the urea is being maintained will vary depending on the dosing of the gas into the exhaust, it is very hard to maintain a stable reaction and ammonia concentration within the hydrolysis gas will vary as the relative proportions of the hydrolysis gas, namely ammonia, carbon dioxide and steam will vary dependant on the temperature and pressure at which the reaction takes place. Also, the temperature of the gaseous ammonia leaving the system will be related to the exhaust gas temperature, over which the system has no control, and will thus vary dramatically from minute to minute making it hard to control both the rate of production of the ammonia-containing gas, and the accurate dosing of it as it will be hard to determine its density.

It is known from this document to use a buffer or reservoir to temporarily store some ammonia-containing gas to reduce the dependence on dosing of the reagent on the production rate of ammonia-containing gas at any given time. This is usually advantageous as the addition of the buffer reduces the necessary response speed of the system to transient fluctuations in demand and enables a smaller reactor to be used, the output of which does not necessarily need to match the maximum demand rate for reagent but rather which matches the average demand rate for the reagent. In this way the buffer acts as a dampener between the instantaneously required ammonia-containing gas and the required production rate.

There are however a number of problems with current systems having reservoirs. Firstly - to dose from the reservoir there is required a certain amount of time required to build a sufficient reserve of pressure within the reservoir to enable controlled dosing of it into the exhaust. This generally means that there is a significant time interval on start up of the system before which there is sufficient ammonia containing gas in the reservoir to start dosing. This means that there is a period during start up that the NOx from the engine can not be reduced. As ever more stringent legislation is introduced controlling the total NOX emissions through the engine cycle these current systems will not be able to keep up with start up conditions, else will require complex secondary systems to do so.

The reservoir, valves, sensors and piping need to remain at a high enough temperature such that condensation of the ammonia-containing gasses is prevented. It is desirable that an elevated temperature of these components is achieved as soon as possible after start up, preferably before ammonia containing gas is passed through them.

The temperature of the gas leaving the reactor is dictated by the exhaust gas temperature it can be as high as 600 degrees C. This creates numerous problems for components, used in or on the buffer and generally within the system in association with the control of the ammonia-containing gas at high temperature and pressures, which commonly experience short lives and premature failure under these conditions. As ammonia is a hazardous substance and as vehicles, are prevalent urban areas there is a potential risk to health from ammonia leakages caused by the failure of these components.

In addition, there are modes of operation, particularly under highly transient conditions in which the dampening effect is disadvantageous and the reservoir may run empty if a reactor sized for average demand is used and is unable to replenish it fast enough.

Complex control of the addition of the ammonia-containing gas to the exhaust is required as the pressure and the temperature of the gas in the buffer can vary widely and the flow rate through a dosing valve will be dependent on both of these variables. This leads to the necessity to use overly complex control algorithms to dose the required amount of reagent at a given time.

It is the object of the various aspects of the present invention to mitigate some of the above problems.

According to a first aspect of the present invention there is provided an apparatus for generating gaseous hydrolysis product comprising ammonia, formed by the hydrolysis of an aqueous solution of urea (as hereinbefore defined) at elevated temperature and pressure, and feeding it into the exhaust gas of an IC engine as it flows through the exhaust system of the engine, the apparatus comprising:

a) a housing having an inlet for the exhaust gas and an outlet for the exhaust gas;

b) a reaction vessel located at least partially within the housing between the inlet and the outlet for containing an aqueous solution of urea and arranged such that, in use, the vessel and therefore the urea solution become heated by means of heat exchange with the exhaust gas as it flows from the inlet to the outlet;

c) a urea solution inlet to the reaction vessel and a gaseous hydrolysis product outlet from the reaction vessel;

d) a reservoir mounted remotely from the housing for receiving and storing the gaseous hydrolysis product;

e) a valve between the outlet from the reaction vessel and the reservoir adapted to permit the contents of the reaction vessel, in use, to attain an elevated pressure as it becomes heated, and to discharge gaseous hydrolysis product therethrough into the reservoir;

f) a conduit for interconnecting the reservoir and the exhaust system, the conduit including a valve to selectively control the feed of hydrolysis product stored in the reservoir into the exhaust gas *via* the conduit; and wherein

the reservoir further comprises a temperature sensor, to monitor the temperature within the reservoir, and a heating means, operable in response to the temperature as sensed by the temperature sensor being below a predetermined temperature, to heat the reservoir.

Preferably the valves are located on or adjacent to the reservoir at its remote location such that they are protected from direct exposure from the hot exhaust gasses which, reaching temperatures in excess of 600 degrees C, can severely degrade the life of seals in these components. The reduction in the operating ambient temperature of the valves achieved by locating them remotely from the exhaust gas environment means that standard high temperature components can be used whereby specially engineered valves are not needed.

Preferably the reservoir is located such that the temperature of the gas entering it is at a temperature of from 150 to 220 degrees C, the lower limit of 150 degrees approximately corresponding to the aforesaid predetermined temperature. The valves are heated by these gases and so the problem of condensation and the formation of solids that can block them is prevented.

As the reservoir is located remotely from the exhaust conduit it will not automatically become heated by the exhaust gas when the engine is started, but will remain at the ambient temperature of its environment, at least until hot hydrolysis gasses start to enter it from the reaction vessel. As the ambient temperature of the reservoir in this initial time period may vary from around -30 degrees C to 50 degrees C depending on the geographical location of the vehicle there is a danger that the exhaust gasses entering the reservoir may immediately condense which would prevent them from being used for reducing the NOx in the exhaust gas. The heating means is therefore operable to heat the reservoir so that, at start up, it quickly approaches its desired minimum temperature, and thereafter to maintain the reservoir at or above that minimum temperature during normal operation of the IC engine. The temperature sensor detects the temperature of the reservoir and if it is below its operational temperature a signal is sent to the heater to activate it. This will occur under most conditions upon start up, and periodically thereafter, depending on the ambient conditions and the rate of production and the temperature of hydrolysis gas. By maintaining the gas within a limited temperature range the control system for adding the hydrolysis gas to the exhaust need not cope with great fluctuations in temperature and a simpler control regime can therefore be used. In addition, controlling the temperature of the gas entering the reservoir is to be from 150 to 220 degrees C means that standard components can be used and component failure due to the temperature will be vastly reduced thereby effecting a more durable safer working system.

Preferably, once the reservoir reaches operational temperature the heating means is switched off and the heat input from the hot incoming hydrolysis gas is sufficient to keep the reservoir within its required temperature range. To assist this the reservoir is preferably insulated about its exterior such that temperature loss is reduced. This is particularly important where the IC engine is in a cold environment where there will be a larger temperature difference between the temperature of the reservoir and the ambient temperature.

Preferably the conduit connecting the reaction vessel and the reservoir is also heated by the, or an alternative, heating means.

Optionally the reservoir may be placed sufficiently close to the exhaust system that there is some, but not excessive, heat transfer from the exhaust system to the reservoir, thereby reducing the power requirement of the heating means.

Where the desired storage temperature of the reservoir is below the temperature of the incoming gas then the reservoir may have additional means of losing heat to the environment. This may be simply by heat transfer to the environment by radiation, cooling by air being drawn over the exterior of the reservoir (either forced or by convection) or alternatively a cooling circuit may be provided, operable to remove excess heat and maintain the reservoir at a temperature less than the temperature of the incoming exhaust gas. Preferably this cooling circuit is either a part of the engine cooling circuit or has a heat exchanger to transfer heat to the engine cooling or lubrication circuit.

As the apparatus, in its preferred form, can be supplied as essentially one unit, which fits in line in the exhaust, and an associated reservoir, it is simple to fit both for new-build vehicles and as a retrofit to existing ones.

The valve (e) between the outlet from the reaction vessel and the reservoir is adapted to permit the contents of the reaction vessel, in use, to attain an elevated pressure as it becomes heated. The valve may take a number of forms. In one preferred arrangement the valve (e) actuates in response to the pressure within the reaction vessel and preferably periodically discharges gaseous hydrolysis product into the reservoir. This can be an active actuation where the pressure is measured in the reaction vessel and the valve is actuated via a control system depending on the signal received from a pressure transducer situated in the reaction vessel or in an aqueous urea feed line thereto. Alternatively this can be a passive actuation where the valve is self actuating when a preset pressure occurs on its inlet side, i.e. it is a simple mechanical back pressure valve. By maintaining an appropriate pressure within the reactor vessel, preferably substantially constant, the hydrolysis gas that leaves the reactor vessel via the valve (e) has a substantially constant ratiometric mix.

In an alternative preferred arrangement the valve (e) actuates in response to the temperature of the aqueous solution of urea. This is preferably done by measuring the temperature within the aqueous urea solution and actuating the valve in response to the measured temperature. As the reaction occurs within the reaction vessel and the pressure rises the temperature within the solution can also be raised until both are elevated, and as there is a direct relationship between the two, control of the release of the gaseous hydrolysis product can be based on either.

In a preferred arrangement of the present invention the apparatus further comprises a sensor placed within the exhaust gas flow to measure the quantity of NOx therein. The NOx sensor may be upstream of the point of introduction of the ammonia-containing hydrolysis gas or downstream of the SCR catalyst and would either measure the NOx output of the engine or the NOx output of the vehicle respectively. If the NOx output of the engine is measured then the signal is used to predict the required volume of the gaseous hydrolysis product required to be dosed into the gas to effect its removal (i.e. open loop control), whereas if the NOx output of the vehicle is sensed then more or less gaseous hydrolysis product will be dosed into the exhaust gas depending whether the sensed NOx level is above or below a target level (i.e. closed loop control). In an alternative arrangement an ammonia sensor is placed downstream of the SCR catalyst to measure ammonia slip (the amount of ammonia issuing un-reacted from the SCR catalyst). The control system can then sense if too much ammonia-containing hydrolysis gas is being added to the exhaust flow and reduce the amount accordingly.

Preferably the apparatus is close coupled to an SCR catalyst, or optionally is contained within one and the same unitary housing with an SCR catalyst connectable in-line in the exhaust system. Preferably the downstream end of the SCR catalyst is coated with a catalyst that converts any un-reacted ammonia in the exhaust gas so that ammonia is not released into the environment.

Preferably the exhaust gas flowpath between the point of introduction of the hydrolysis product and the SCR catalyst is shaped to induce mixing of the hydrolysis gas with the exhaust gas. Preferably the hydrolysis gas is introduced in a direction substantially perpendicular to the direction of the exhaust gas flow. Preferably a number of radially spaced inlets are situated adjacent to one another substantially perpendicular to the flow of the exhaust gas. Preferably the point of introduction is substantially at the mouth of a truncated conical section of the flowpath and the flow of exhaust gas and hydrolysis gas into the cone induces mixing. Preferably the flowpath between the point of introduction of the hydrolysis gas and the SCR catalyst has at least one substantially 90degree bend causing turbulence in the flowpath further inducing mixing. Optionally the exhaust gas and hydrolysis gas may enter a substantially cylindrical vortex chamber, upstream of the SCR catalyst, substantially perpendicularly to the radius of the chamber and exits the chamber along its central axis, the vortex within the chamber further inducing mixing of exhaust gas and hydrolysis gas.

In a preferred embodiment the heating means comprises an electric heating element in thermal contact with the exterior of the reservoir. In an alternative embodiment the heating means comprises a heating element incorporated into the reservoir body. In a further embodiment the heating means comprises a variable flow of hot exhaust gas which is passed over the reservoir. Preferably the flow of the exhaust gas is controlled by a valve.

Preferably the heating element is connected to an electrical input of the vehicle such that when the vehicle is connected to a source of external power the reservoir is heated. This is especially helpful where the IC engine is onboard a motor vehicle for use in low ambient temperatures. In geographical areas where sub zero temperatures are frequent, many vehicles, in particular passenger and commercial vehicles are connected to an external source of electric power when not in use. This power is used to maintain the engine oil and optionally other temperature sensitive parts of the vehicle at a temperature above the ambient temperature such that the engine can be readily started and, in the context of the present invention, may serve to heat the reservoir as well.

Preferably, the apparatus further comprises an oxidation catalyst through which the exhaust gas flows prior to the addition of the hydrolysis gas. Preferably the oxidation catalyst is sized to oxidise a proportion of the Nitric Oxide in the exhaust gas that a favourable mixture, preferably approximately 50/50, of NO and NO_2 is achieved in the exhaust gas. Preferably the oxidation catalyst, device and SCR catalyst are all contained within one unit having an exhaust inlet and an exhaust outlet and connectible in line in the exhaust system of a vehicle.

Preferably, downstream of the oxidation catalyst is a diesel particulate filter. Preferably the diesel particulate filter is contained in one and the same unit as the oxidation catalyst, device and SCR catalyst.

In use the apparatus is attached via a urea solution inlet line to a urea pump and a urea solution tank. Preferably the tank is provided with a quality sensor to monitor a characteristic of the urea solution and create an alert or render the device inoperable if the urea is out of specification for that particular characteristic, for example if it does not have the correct concentration of urea. Equally the sensor will be able to detect if a different substance, e.g. water or diesel has been deliberately or inadvertently put into the urea solution tank. In one arrangement the pump is integral with the urea solution tank. Preferably the urea tank and urea line between the urea tank and the reaction vessel inlet is heated to prevent urea freezing in the urea line.

Preferably the apparatus further comprises a bypass valve which can selectively control the proportion of the exhaust gas which is in thermal contact with the reactor to control the heat input into it.

According to a second aspect invention there is provided a thermo-hydrolysis reactor for producing ammonia-containing gas by heating an aqueous solution of urea or the like under elevated temperature and pressure, the reactor comprising an elongate vessel having a lower area adapted to receive aqueous urea solution and an upper area adapted to collect gaseous hydrolysis product and an outlet conduit having a gaseous hydrolysis product inlet in the upper area and arranged such that said conduit passes through the aqueous urea solution in the lower area and exits the reactor in its lower region, said reactor being adapted such that, in use, heat transmitted through the walls of the reactor from an external heat source heats the solution therein causing it to hydrolyse producing said ammonia-containing gas.

Preferably the outlet conduit further comprises, external to the reactor, a valve means adapted to cause the pressure in the reactor to rise to a set pressure as it becomes heated and to allow the ammonia-containing gas to exit the reactor above that pressure.

Preferably the valve in the outlet conduit is controllable to vary the pressure in the reactor and whereby the outlet temperature of the gaseous hydrolysis product may be varied by varying the temperature of the aqueous urea solution through which the outlet conduit passes by varying the pressure within the reactor, said aqueous urea solution temperature being dependent on pressure within the reactor.

Preferably the reactor vessel is placed in the exhaust conduit of an IC engine such that in use exhaust gas passes over it thereby heating the solution therein causing it to hydrolyse producing said ammonia-containing gas.

The temperature of the gas in the upper area will vary dependent on the temperature of the exhaust gas and, as this is dependent on exhaust condition will fluctuate. For example the temperature of the exhaust gas of the IC engine of a commercial vehicle may vary approximately between 120 degrees C and 600 degrees C. As the pressure within the reactor is determined by the valve means, the density of the gas, which depends on pressure and temperature, in the upper area of the reactor will vary proportionately to the temperature at any given time. The temperature of the aqueous urea solution will not vary in direct relation to the temperature of the exhaust gas but in relation to the pressure within the reactor. Once it has reached operating conditions, i.e. the reactor is producing ammonia-containing gas and that gas is exiting the reactor via the conduit and the valve means, the temperature of the aqueous solution of urea will remain substantially constant at a temperature which is dependent on the pressure above which the valve means is set to release the ammonia-containing gas. At a pressure of 14-20 bar the temperature will be approximately in the region of from 150 degrees to 220 degrees C. By routing the outlet conduit through the aqueous solution of urea the ammonia-containing gas passing therethrough is cooled to substantially the temperature of the aqueous solution of urea. The temperature of the urea solution within the reactor in the above range is at an ideal temperature to heat the storage vessel and associated valves of the first aspect of the invention to prevent condensation, without allowing them to rise to such a temperature that mechanical failure of those components is greatly accelerated.

According to a third aspect of the invention there is provided a reactor according to the second aspect of the invention used in the apparatus according to the first aspect of the invention.

According to a fourth aspect of the present invention there is provided a method of pre-heating the components of an ammonia production apparatus for use in an SCR process prior to the ammonia production system reaching operating conditions, the method comprising the steps of:

a) heating an enclosed hydrolysis reactor having an aqueous urea solution inlet and a gaseous hydrolysis product outlet and containing an aqueous solution of urea such that its pressure and temperature increase;

b) monitoring the temperature of the aqueous urea solution in the reactor;

c)when the temperature reaches a specific temperature in excess of 100 degrees Centigrade, temporarily opening an outlet valve in the gaseous hydrolysis product outlet for a short period such that the pressure within the reactor drops thereby causing water to rapidly vaporise into steam;

d) allowing the steam to pass through the outlet valve, thereby heating it and any components downstream thereof; and

e) closing the outlet valve to allow the temperature and pressure of the hydrolysis reactor to increase to said operating conditions.

Preferably step c) is carried out when the temperature of the aqueous urea solution is detected to be in the range 100 to 120 degrees, more preferably 103 to 109 degrees centigrade.

According to a fifth aspect of the present invention there is provided an apparatus for generating gaseous hydrolysis product comprising ammonia, formed by the hydrolysis of an aqueous solution of urea at elevated temperature and pressure, and feeding it into the exhaust gas of an IC engine as it flows through the exhaust system of the engine, the apparatus comprising:

a) a housing having an inlet for the exhaust gas and an outlet for the exhaust gas;

b) a reaction vessel located at least partially within the housing between the inlet and the outlet for containing an aqueous solution of urea and arranged such that, in use, the vessel and therefore the urea solution become heated by means of heat exchange with the exhaust gas as it flows from the inlet to the outlet;

c) a urea solution inlet to the reaction vessel and a gaseous hydrolysis product outlet from the reaction vessel;

d) a reservoir for receiving and storing gaseous hydrolysis product;

e) a first valve between the outlet from the reaction vessel and the reservoir adapted to permit the contents of the reaction vessel, in use, to attain an elevated pressure as it becomes heated, and to discharge gaseous hydrolysis product therethrough into the reservoir;

f) a first conduit for interconnecting the reservoir and the exhaust system, the first conduit including a second valve to selectively control the feed of hydrolysis product stored in the reservoir into the exhaust gas *via* the first conduit; and

g) a second conduit interconnecting the reaction vessel and the exhaust system, the second conduit including a third valve to selectively control the feed of hydrolysis product directly from the reactor into the exhaust gas *via* the second conduit.

According to a sixth aspect of the present invention there is provided a method of operating the apparatus according to the fifth aspect of the invention comprising the steps of:

a) running the engine causing hot exhaust to pass over the reaction vessel causing its temperature and pressure to raise until it reaches operating conditions;

b) measuring the pressure within the reaction vessel and within the reservoir;

c) once the pressure within the reaction vessel reaches a first predetermined pressure, controllably opening the third valve to allow some of the gaseous hydrolysis product to pass *via* the second conduit into the exhaust gas directly from the reaction vessel;

d) once the pressure in the reaction vessel reaches a second predetermined pressure higher than the first predetermined pressure, allowing the first valve to open whereby excess gaseous hydrolysis product passes from the reaction vessel into the reservoir *via* said first valve thereby causing the pressure within the reservoir to rise; and

e) once the pressure within the reservoir reaches a predetermined pressure, closing the third valve and controllably opening the second valve to dose the ammonia-containing hydrolysis gas from the reservoir into the exhaust gas.

Preferably in step d) the first valve opens once the pressure in the reactor exceeds a second set pressure in the region 12-18 bar, more preferably in the range 14-16 bar.

Preferably in step e) the reservoir starts to dose *via* the third valve once the pressure therein reaches a predetermined pressure in the range of 4-8 bar, most preferably 6 bar.

Preferably, following step e) the method further comprises the step of,
f) if the pressure within the reservoir should fall below a predetermined pressure and the pressure within the reactor is above the first predetermined pressure, closing the second valve and opening the third valve such that ammonia is dosed directly from the reaction vessel into the exhaust bypassing the reservoir; and simultaneously above a predetermined pressure within the reaction vessel, allowing the first valve to open and any excess gaseous hydrolysis produce to escape from the reaction vessel into the reservoir *via* said first valve thereby causing the pressure within the reservoir to rise; and
g) once the pressure within the reservoir reaches a predetermined pressure, closing the third valve and controllably opening the second valve to dose the ammonia-containing hydrolysis gas from the reservoir into the exhaust system of the IC engine to flow with the exhaust gas through the SCR catalyst.

Preferably the predetermined pressure in step f) is in the range of 4-8 bar, most preferably 6 bar.

By using this method, in operation the apparatus can benefit from the advantages of having a reservoir vessel, i.e. the reservoir can dampen the changing demands on the needs of the reactor vessel thereby enabling it to usually operate under substantially constant conditions (of pressure and temperature) whilst avoiding the problem of having to wait for a larger reservoir to fill to a minimum pressure before being able to use the output of the reaction vessel. The present invention can therefore reduce more NOx in the exhaust gas early after start up than previous systems containing reservoirs.

Occasionally there may be peaks of very high ammonia-containing gas demand for short periods. For example, an IC engine on a commercial vehicle will experience a sudden increase in load and therefore NOx output as it climbs a steep hell. Preferably under these extreme conditions both the second and the third valves open simultaneously to achieve the required flow rate of ammonia-containing hydrolysis gas into the exhaust system. By opening both the second and the third valve to dose under extreme conditions the second valve can be optimised dosing flow for the average operating conditions thereby offering more accurate control during the majority of operating conditions of the IC engine and any shortfall under extreme operating conditions can be made up by flow through the third valve.

Equally, in some conditions there may be an excess of ammonia being produced and not used quickly enough resulting in a full reservoir and a continued rising pressure in the reaction vessel, one such condition would be in a long downhill descent following a steep climb. As a safety feature to safely enable the system to operate safely under these conditions there is provided, according to a seventh aspect of the invention, a system for generating gaseous hydrolysis product comprising ammonia, formed by the hydrolysis of an aqueous solution of urea (as hereinbefore defined) at elevated temperature and pressure, and feeding it into the exhaust gas of an IC engine as it flows through the exhaust system of the engine, the apparatus comprising:

a) a housing having an inlet for the exhaust gas and an outlet for the exhaust gas;

b) a reaction vessel located at least partially within the housing between the inlet and the outlet for containing an aqueous solution of urea and arranged such that, in use, the vessel and therefore the urea solution become heated by means of heat exchange with the exhaust gas as it flows from the inlet to the outlet;

c) a urea solution inlet to the reaction vessel and a gaseous hydrolysis product outlet from the reaction vessel;

d) a reservoir for receiving and storing the gaseous hydrolysis product;

e) a valve between the outlet from the reaction vessel and the reservoir adapted to permit the contents of the reaction vessel, in use, to attain an elevated pressure as it becomes heated, and to discharge gaseous hydrolysis product therethrough into the reservoir;

f) a conduit for interconnecting the reservoir and the exhaust system, the conduit including a valve to selectively control the feed of hydrolysis product stored in the reservoir into the exhaust gas *via* the conduit; and

g) a conduit leading from the reaction vessel, or inlet thereof, to an accumulator wherein;

When the pressure within the reactor rises above a predetermined pressure, the aqueous urea solution therein passes from the reaction vessel into the accumulator and, once the pressure within the reservoir falls below the predetermined pressure, fluid is ejected from the accumulator back into the reactor until the accumulator is substantially empty.

In a preferred embodiment the accumulator is a nitrogen bladder accumulator. Preferably the accumulator has a working pressure of 25 bar, i.e. if the pressure within the reaction vessel rises above 25 bar the accumulator receives aqueous urea solution from the reaction vessel to prevent its pressure rising further.

Preferably the reaction vessel also contains a pressure relief valve arranged to vent the contents to atmosphere, should their pressure rise above a second predetermined pressure, and the working pressure of the accumulator is below the pressure of the pressure relief valve.

the reservoir further comprises a temperature sensor, to monitor the temperature within the reservoir, and a heating means, operable in response to the temperature as sensed by the temperature sensor being below a predetermined temperature, to heat the reservoir.

According to an eighth aspect of the present invention there is provided a method of controlling the output flow rate, through a pressure control valve, of a thermo-hydrolysis reactor for producing ammonia-containing gas by heating an aqueous solution of urea or the like contained in the lower section thereof, the reactor adapted to be placed in the exhaust conduit of an IC engine such that, in use, heat transmitted through the walls of the reactor from exhaust gas passing through the exhaust conduit heats the solution therein causing it to hydrolyse producing said ammonia-containing gas, the method comprising the steps of:

a) measuring the temperature of the exhaust gas; and

b) increasing or decreasing the pressure of the ammonia-containing gas within the reactor to control the temperature of the aqueous solution of urea in the lower section of the reactor thereby varying the temperature difference between the aqueous solution of urea and the exhaust gas to control the rate of heat transfer into the reactor.

As the rate of conversion of the aqueous urea solution to gaseous medium is dependant on the rate of heat transfer into it, and, at a specific pressure the output flow rate through the pressure control valve is dependent on the rate of conversion of the aqueous urea solution to gaseous medium, by controlling the rate of heat transfer into the reactor the output flow rate of the reactor is also controlled.

Preferably when the demand for ammonia-containing gas decreases the pressure control valve is operable to increase the pressure within the reactor to reduce the temperature difference between the aqueous solution of urea and the exhaust gas and therefore reduce rate of heat transfer into the reactor slowing, or temporarily stopping, its output.

Preferably when the demand for ammonia-containing gas increases the pressure control valve is operable to lower the pressure within the reactor to increase the temperature difference between the aqueous solution of urea and the exhaust gas and therefore increase rate of heat transfer into the reactor increasing its output.

Preferably the reactor pressure is always maintained within an operational pressure range. Preferably the operational pressure range is 8 bar to 25 bar.

When the pressure is controlled to retard the output flow from the reactor the actual hydrolysis reaction occurring therein does not stop, rather it continues but the discharge of gaseous product from the reactor is temporarily stopped

It will be obvious to anyone skilled in the art that any one the various aspects of the invention may be used in combination with one or more of the other aspects of the invention.

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

Figure 1 is an apparatus in accordance with the first aspect of the invention;

Figure 2 is a reservoir vessel apparatus of the first aspect of the invention;

Figures 3 and 4 are alternative embodiments of the first aspect of the invention;

Figure 5 is a reactor in accordance with the second and seventh aspects of the invention and suitable for use in the first aspect of the invention; and

Figure 6 is a diagram of an apparatus in accordance with the fifth aspect of the invention and operable in accordance with the 6th aspect of the invention.

Referring to Figures 1 and 2 an apparatus for reducing the NOx in the exhaust gasses of the IC engine of a commercial vehicle is shown. The system has a housing 102 having an inlet 104 for the exhaust gas and an outlet 106 for the exhaust gas and which is connectable inline in the exhaust system of the IC engine. The housing 102 contains within a substantially vertical section 108 thereof a reaction vessel (described below in relation to Figure 5) for containing an aqueous solution of urea. In use, the reaction vessel and therefore the urea solution within it become heated by means of heat exchange with the exhaust gas as it flows from the inlet to the outlet. The reaction vessel has an inlet conduit 110 for the supply of the aqueous solution of urea to the reaction vessel and has an outlet conduit 112 for the removal of gaseous hydrolysis product from the reaction vessel. The outlet conduit 112 leads to a reservoir 200 via an inlet valve 202. The reservoir 200 comprises a buffer vessel 204 housed within a reservoir housing 206. The area between the buffer vessel 204 and the reservoir housing 206 is filled with an insulating material (not shown). The reservoir 200 has a heating element 208 therein which is controllable in response to temperature sensor 210 to maintain the temperature within the reservoir substantially stable. The heater 208 is controlled to keep the temperature above 180 degrees C, i.e. control the lower temperature of the reservoir 200, and the temperature of the exhaust gasses entering via reaction vessel outlet conduit 118 control the upper temperature of the reaction vessel. As described in detail below, the temperature of the gas entering the reservoir 200 is maintained substantially constant at about 200 degrees C, therefore resulting in a reservoir temperature of between 180 to 200 degrees C. Maintaining the reservoir 200 and therefore its associated components at these temperatures, which are substantially lower that the exhaust temperature, enables standard high temperature components to be used and reduces the likelihood of failure for the components as it eliminates constant variation in temperature. The heater 208 shown is a simple electrical heating element and is powered in use by the vehicles electrical system. The heater 208 is arranged such that if the vehicle is connected to an auxiliary power source (as is common during shut down periods in cold climates to keep the engine oil heated) to maintain the reservoir 200 in a heated state. Heating of the reservoir 200 from auxiliary power is operable to maintain the reservoir within a temperature range which may be lower than its operational temperature range. The reservoir 200 has an outlet valve 212 which controls the flow of the hydrolysis gas from the reservoir 200 to the exhaust of the engine via a conduit 114. The valve 212 is operable in response to a demand signal to provide the NOX containing exhaust gas with the required amount of hydrolysis gas to pass therewith through an SCR catalyst to effectively reduce the NOx therein. The conduit 114 terminates within the housing 102 which is connectable inline in the exhaust. The reservoir 200 has a safety relief valve 214 which is operate to relieve the pressure within the reservoir should for any reason it rise to dangerous levels. The reservoir 200 is also provided with a pressure transducer 216 to measure the pressure within the reservoir. The pressure of the gas within the reservoir measured by transducer 216 is used to calculate the required opening of the outlet valve 212 such that the requisite mass flow of hydrolysis gas passes therethrough.

Figure 3 shows an alternative arrangement of the of apparatus shown in Figure 1 wherein after the hydrolysis gas is introduced into the mouth of a truncated conical section immediately downstream of an oxidation catalyst 302 the housing turns through two 90° bends, the truncated conical section and the 90° bends acting to induce some turbulence to aid mixing the hydrolysis gas fully with the exhaust gas. Downstream the second bend the apparatus is coupled to an SCR catalyst 304 by coupling 306.

Referring to Figure 4 an alternative method of heating the reservoir 200 is shown comprising an exhaust gas feed pipe 402 having a variable valve 404 therein, the exhaust gas feed pipe 402 leading to the reservoir and passing between the reservoir housing 206 an the buffer vessel 204 (both shown on Figure 2). The valve 404 is operable to allow a variable flow of hydrolysis gas to pass over the buffer vessel thereby maintaining it in a heated state.

Referring to Figure 5 a thermo-hydrolysis reactor is shown comprising a reaction vessel 500 having a pressure resistant body 502 for containing an aqueous solution of urea 504 in its lower section. The urea solution is fed into the reaction vessel via conduit 506 by a pump (not shown). A level sensor 514 is provided to enable the reactor to be filled to the desired level. In use the reaction vessel is placed in the exhaust gas flow of an IC engine, for example, this reactor may be placed in the upright section of the housing 108 of Figure 1. As the hot exhaust gasses pass over it, heat is transferred to the aqueous urea within it causing the temperature to rise. As the temperature rises it will pass the boiling point of water at which time some of the solution will start to vaporise. In addition as the temperature rises the urea solution will start to hydrolyse and break down to form ammonia and carbon dioxide which will also come out of the solution. The result is that a head of gas will start to form in the upper section of the reactor 508 above the liquid aqueous solution of urea. An outlet 510 for the gaseous hydrolysis produce extends from the upper region of the reactor above the liquid level substantially vertically downwards through the aqueous solution of urea 504 and exits the bottom of the reactor body 502. A valve 512 controls the flow of the gaseous hydrolysis product out of the reactor 502 and is operable to maintain an elevated pressure within the reactor body 502. A baffle 516 is provided in the upper section of the reactor 508 which slopes downwards towards the centre of the reactor where it has an opening to allow both the gaseous hydrolysis product and the outlet conduit 510 to pass therethrough. The baffle 516 prevents any liquid splashes from the lower section of the reactor body 502 to enter the outlet conduit 510 ensuring no liquid leaves the reactor. The reaction vessel 500 is further provided with a pressure sensor 518 and a temperature sensor 520.

The temperature in the reactor will vary from the liquid aqueous solution to the gaseous hydrolysis product. The temperature of the liquid is controlled by the pressure in the upper section 508, as at its boiling point at its temperature will remain constant and the boiling point of a liquid is dependent on its pressure. However, the reactor 500 is designed to be placed in the exhaust conduit of an IC engine and the gas temperatures passing through the exhaust conduit will vary from about 120 degrees to 500 or 600 degrees C and are typically in the region of 250-230 degrees C. Providing that the boiling point of the liquid is below the temperature of the exhaust gas, then the temperature of the liquid will remain constant and the temperature of the gas in the upper section of the reservoir 508 will vary, closely following the exhaust gas temperature. By leading the outlet conduit from the upper section 508 through the aqueous solution of urea, the gaseous hydrolysis product will give up heat into the urea in through the conduit wall as it passes through the liquid. This will result in the temperature of the gaseous product exiting the reaction vessel 500 being substantially at the temperature of the aqueous solution of urea and therefore the reactor will produce a product having a substantially constant temperature, despite fluctuations in the exhaust gas temperature.

In one mode of operation the valve 512 is operable to vary the pressure within the reaction vessel 500 to control the production rate of gaseous product therein. At a specific pressure the temperature of the aqueous solution of urea will remain substantially constant and the vaporisation of the liquid medium into the gaseous medium is dictated by the rate of heat input into the liquid medium. As stated temperature of the liquid is controlled by the pressure in the upper section 508 of the reactor, the greater the pressure the greater the temperature, and the rate of heat input is controlled by the difference in temperature between the liquid medium and the exhaust gas heating the exterior of the reactor body 502. Therefore, by increasing the pressure in the reactor by controlling valve 512 the temperature of the liquid in the reactor can be caused to increase thereby reducing the temperature difference between the liquid inside the reaction vessel 500 and the exhaust gasses outside the reactor thereby slowing the rate of heat transfer and therefore the rate production rate of gaseous product therein. If the pressure is allowed to rise substantially high enough that the boiling point of the liquid is equal to the exhaust gas temperature then there should be no heat transfer and therefore the production rate of gaseous product can be temporarily halted if necessary. Pressure 518 and temperature 520 sensors monitor the temperature and pressure within the reactor and ensure, via a control system (not shown) that the valve 512 is controlled to ensure that maximum operating pressure is not exceeded.

Referring to Figure 6 an apparatus for reducing the NOx content of the exhaust gas of an IC engine is shown. The apparatus comprises a reaction vessel 602 as described in relation to Figure 5. The outlet of the reaction vessel 602 has two valves 604 606 therein leading to a reservoir and the exhaust conduit 610 respectively. The valves 604, 606 are shown in a common outlet from the reaction vessel 602 but may of course alternatively have individual outlets. The reservoir 608 has a conduit 612 leading therefrom to the exhaust conduit 610 and having a valve 614 therein.

In use the reaction vessel is located in the exhaust conduit 610 such that on start up of the system the hot exhaust gas heats the reaction vessel 602 causing the contents to start to hydrolyse and the pressure therein to rise. The temperature and pressure within the reaction vessel are monitored by the temperature and pressure sensors 616, 618. When the temperature exceeds 100 degrees the water in the solution will start to boil and the pressure will increase enabling the temperature to rise above 100 degrees. Once the temperature has risen to 105 degrees, and therefore a small head of pressure has built, all the valves in the system are opened to allow the steam to pass through the valves 606, 604, 614 and the reservoir 608 thereby pre-heating them with steam prior to any of the ammonia-containing gas passing through. Simultaneously with this the heating element 620 is energised to input additional heat to the reservoir 608. The reservoir 608 is insulated by an insulating layer 622. Once the valves have been open for a short period and have been warmed by the steam passing therethrough, the valves are all closed and the pressure and temperature in the reaction vessel 602 allowed to continue to rise. The temperature within the reservoir is monitored by temperature sensor 626 and the sensed temperature is used to selectively control the heater 622 to heat the reservoir to at least 150 degrees and to maintain it above that temperature. Within a couple of minutes the reaction vessel 602 will be at operational pressure of around 16 bar and will be producing ammonia-containing hydrolysis gas. Once the operational pressure has been reached, valve 606 is controllably opened to dose the hydrolysis gas directly into the exhaust conduit 610. By dosing directly into the exhaust conduit 610 from the reaction vessel 602 the ammonia-containing gas can be used to reduce the NOx in exhaust gas passing therethrough much sooner that if it were first introduced into the reservoir 608 as there is no need to build up reservoir pressure. This enables more NOx to be reduced across the whole cycle of the engine from start up to shut down and vastly reduces the time during start up during which it is not possible to dose into the exhaust with current systems having reservoirs. As demand during start up is generally less than average, and as the apparatus takes a while to reach normal operational temperatures, the pressure and temperature in the reaction vessel 602 will continue to rise, even as the hydrolysis product is being dosed. Once the pressure in the reaction vessel 602 exceeds higher set pressure of eighteen bar the valve 604 leading to the reservoir opens and allows any pressure in excess eighteen bar to pass through the valve 604 into the reservoir 608, maintaining the pressure within the reaction vessel 602 at a maximum pressure of the higher set pressure. During this time the system continues to simultaneously to dose from the reaction vessel 602 directly into the exhaust conduit 610. During this period, should the pressure in the reaction vessel 602 fall below the higher set pressure of eighteen bar, valve 604 will temporarily close until such time as the pressure in the reaction vessel 602 once again rises above eighteen bar. Over a period of time, which will vary dependant on the exhaust gas parameters, the pressure in the reservoir 608 will build as a result of the gas passing into it through valve 604 until such point as there is sufficient pressure in the reservoir to dose directly from it. Once the pressure in the reservoir, which is measured by reservoir pressure transducer 624 is six bar valve 606 closes and valve 614 is controllably opened to allow a controlled flow of ammonia containing gas to flow from the reservoir 608 into the exhaust conduit 610 via the valve 614. A valve 606 is closed all the ammonia-containing gas from the reaction vessel 602 flows into the reservoir 608 allowing the pressure to continue to build therein. The apparatus is then in its normal operational mode wherein the reservoir 608 acts as a buffer to cope with immediate fluctuations in demand. If the flow through valve 614 is ever limited due to low pressure within the reservoir 608 the apparatus can either return to its previous mode of operation wherein it doses directly from the reaction vessel 602 into the exhaust conduit 610 and cycles valve 604 to refill the reservoir 608 to working pressure, or alternatively valve 606 may be partially opened to supplement the flow passing through valve 614.

Claims

1 An apparatus for generating a gaseous hydrolysis product comprising ammonia, formed by the hydrolysis of an aqueous solution of urea at elevated temperature and pressure, and feeding it into the exhaust gas of an IC engine as it flows through the exhaust system of the engine, the apparatus comprising:

a) a housing having an inlet for the exhaust gas and an outlet for the exhaust gas;

b) a reaction vessel located at least partially within the housing between the inlet and the outlet for containing an aqueous solution of urea and arranged such that, in use, the vessel and therefore the urea solution become heated by means of heat exchange with the exhaust gas as it flows from the inlet to the outlet;

c) a urea solution inlet to the reaction vessel and a gaseous hydrolysis product outlet from the reaction vessel;

d) a reservoir mounted remotely from the housing for receiving and storing the gaseous hydrolysis product;

e) a valve between the outlet from the reaction vessel and the reservoir adapted to permit the contents of the reaction vessel, in use, to attain an elevated pressure as it becomes heated, and to discharge gaseous hydrolysis product therethrough into the reservoir;

f) a conduit for interconnecting the reservoir and the exhaust system, the conduit including a valve to selectively control the feed of hydrolysis product stored in the reservoir into the exhaust gas via the conduit; and wherein

the reservoir further comprises a temperature sensor, to monitor the temperature within the reservoir, and a heating means, operable in response to the temperature as sensed by the temperature sensor being below a predetermined temperature, to heat the reservoir.

2 The apparatus according to claim 1 wherein the valves are located on or adjacent to the reservoir at its remote location.

3 The apparatus according to claim 1 or claim 2 wherein the temperature of the gas entering the reservoir is controlled to be from 150 to 220 degrees C.

4 The apparatus according to any one of claims 1 to 3 wherein once the reservoir reaches operational temperature the heating means is switched off and the heat input from the hot exhaust gas is sufficient to keep the reservoir within its required temperature range.

5 The apparatus according to any one of claims 1 to 4 wherein the reservoir is insulated about its exterior.

6 The apparatus according to any one of claims 1 to 5 wherein the conduit connecting the reaction vessel and the reservoir is heated by the or an alternative heating means.

7 The apparatus according to any one of claims 1 to 6 wherein the valve (e) actuates in response to the pressure measured within the reaction vessel.

8 The apparatus according to any one of claims 1 to 6 wherein the valve (e) is self actuating when a preset pressure occurs on its inlet side.

9 The apparatus according to any one of claims 1 to 6 wherein the valve (e) actuates in response to the temperature of the aqueous solution of urea.

10 The apparatus according to any one of claims 1 to 9 wherein the apparatus further comprises a sensor placed within the exhaust gas flow to measure the quantity of NOx therein.

11 The apparatus according to any one of claims 1 to 10 wherein an ammonia sensor is placed downstream of the SCR catalyst to measure ammonia slip.

12 The apparatus according to any one of claims 1 to 11 wherein the reaction vessel is contained within one and the same unitary housing with an SCR catalyst connectable in-line in the exhaust system.

13 The apparatus according to any one of claims 1 to 12 wherein the downstream end of the SCR catalyst is coated with a catalyst to oxidise any un-reacted ammonia in the exhaust gas.

14 The apparatus according to any one of claims 1 to 13 wherein the ammonia gas is introduced in a direction substantially perpendicular to the direction of the exhaust gas flow.

15 The apparatus according to claim 14 wherein number of radially spaced inlets are situated adjacent one another substantially perpendicular the flow

16 The apparatus according to any one of claims 1 to 13 wherein the exhaust gas flowpath between the point of introduction of the hydrolysis gas and the SCR catalyst is shaped to induce mixing of the hydrolysis gas with the exhaust gas.

17 The apparatus according to claim 16 wherein the point of introduction of the ammonia-containing gas is substantially at the mouth of a truncated conical section of the flowpath and the flow of exhaust gas and hydrolysis gas into the cone induces mixing.

18 The apparatus according to claim 16 wherein the flowpath between the point of introduction of the hydrolysis gas and the SCR catalyst has at least one substantially 90degree bend causing turbulence in the flowpath further inducing mixing.

19 The apparatus according to claim 16 wherein subsequent introduction of the hydrolysis gas, the exhaust gas and hydrolysis gas enter a substantially cylindrical vortex chamber, upstream of the SCR catalyst, substantially perpendicularly to the radius of said chamber and exit the chamber along its central axis, the vortex within the chamber further inducing mixing of exhaust gas and hydrolysis gas.

20 The apparatus according to any one of the preceding claims wherein the heating means comprises an electric heating element in thermal contact with the exterior of the reservoir.

21 The apparatus according to any one of claims 1 to 19 wherein the heating means comprises an electric heating element in located internally to the reservoir.

22 The apparatus according to any one of claims 1 to 19 wherein the heating means comprises a heating element incorporated into the reservoir body.

23 The apparatus according to any one of claims 20 to 22 wherein the heating element is connected to an electrical input of the vehicle such that when the vehicle is connected to a source of external power the reservoir is heated.

24 The apparatus according to any one of claims 1 to 19 wherein the heating means comprises a variable flow of hot exhaust gas which is passed over the reservoir.

25 A thermo-hydrolysis reactor for producing ammonia-containing gas by heating an aqueous solution of urea or the like, the reactor comprising an elongate vessel

having a lower area adapted to receive aqueous urea solution and an upper area adapted to collect gaseous hydrolysis product and an outlet conduit, said outlet conduit having a gaseous hydrolysis product inlet in the upper area of the reactor and being arranged such that it passes through the aqueous ammonia solution in the lower area of the reactor and exits the reactor in its lower region, said reactor being adapted such that, in use, heat transmitted through the walls of the reactor from an external heat source heats the solution therein causing it to hydrolyse producing said ammonia-containing gas.

26 The reactor vessel according to Claim 25 wherein gaseous hydrolysis product passing through the outlet conduit is cooled to substantially the temperature of the aqueous urea solution through which said conduit passes.

27 The reactor according to claim 25 or claim 26 further comprising a valve means adapted to cause the pressure in the reactor to rise to a set pressure as it becomes heated and to allow the ammonia-containing gas to exit the reactor above that pressure.

28 The reactor according to claim 27 wherein the valve is controllable to vary the pressure in the reactor whereby the outlet temperature of the gaseous hydrolysis product may be varied by varying the temperature of the aqueous urea solution in dependence upon the variation of pressure within the reactor.

29 The reactor vessel according to Claim 25 or 26 adapted to be placed in the exhaust conduit of an IC engine such that in use exhaust gas passes over it thereby heating the solution therein causing it to hydrolyse producing said ammonia-containing gas.

30 The apparatus according to any one of claims 1 to 24 having a reaction vessel according to any one of claims 25 to 30

31 A method of pre-heating the components of an ammonia production apparatus for use in an SCR process prior to the ammonia production apparatus reaching operating conditions, the method comprising the steps of:

a) heating an enclosed hydrolysis reactor having an aqueous urea solution inlet and a gaseous hydrolysis product outlet and containing an aqueous solution of urea such that its pressure and temperature increase;

b) monitoring the temperature of the aqueous urea solution in the reactor;

c)when the temperature reaches a specific temperature in excess of 100 degrees Centigrade, temporarily opening an outlet valve in the gaseous hydrolysis product outlet for a short period such that the pressure within the reactor drops thereby causing water from the aqueous solution of urea to rapidly vaporise into steam;

d) allowing the steam to pass through the outlet valve, thereby heating it and any components downstream thereof; and

e) closing the outlet valve to allow the temperature and pressure of the hydrolysis reactor to rise.

32 The method according to claim 31 wherein step c) is carried out when the temperature of the aqueous urea solution is detected to be in the range 100 to 120 degrees,

33 The method according to claim 32 wherein step c) is carried out when the temperature of the aqueous urea solution is detected to be in the range 103 to 109 degrees centigrade.

34 An apparatus for generating gaseous hydrolysis product comprising ammonia, formed by the hydrolysis of an aqueous solution of urea at elevated temperature and

pressure, and feeding it into the exhaust gas of an IC engine as it flows through the exhaust system of the engine, the apparatus comprising:

a) a housing having an inlet for the exhaust gas and an outlet for the exhaust gas;

b) a reaction vessel located at least partially within the housing between the inlet and the outlet for containing an aqueous solution of urea and arranged such that, in use, the vessel and therefore the urea solution become heated by means of heat exchange with the exhaust gas as it flows from the inlet to the outlet;

c) a urea solution inlet to the reaction vessel and a gaseous hydrolysis product outlet from the reaction vessel;

d) a reservoir for receiving and storing gaseous hydrolysis product;

e) a first valve between the outlet from the reaction vessel and the reservoir adapted to permit the contents of the reaction vessel, in use, to attain an elevated pressure as it becomes heated, and to discharge gaseous hydrolysis product therethrough into the reservoir;

f) a first conduit for interconnecting the reservoir and the exhaust system, the first conduit including a second valve to selectively control the feed of hydrolysis product stored in the reservoir into the exhaust gas via the first conduit; and

g) a second conduit interconnecting the reaction vessel and the exhaust system, the second conduit including a third valve to selectively control the feed of hydrolysis product directly from the reactor into the exhaust gas via the second conduit.

35 A method of operating the apparatus according to claim 34 comprising the steps of:

a) starting the engine causing hot exhaust to pass over the reaction vessel causing its temperature and pressure to rise;

b) measuring the pressure within the reaction vessel and within the reservoir;

c) once the pressure within the reaction vessel reaches a first predetermined pressure, controllably opening the third valve to allow some of the gaseous hydrolysis product to pass via the second conduit into the exhaust gas directly from the reaction vessel;

d) once the pressure in the reaction vessel passes a pressure above a second predetermined pressure higher than said first predetermined pressure, allowing the first valve to open whereby gaseous hydrolysis product passes from the reaction vessel into the reservoir *via* said first valve thereby causing the pressure within the reservoir to rise; and

e) once the pressure within the reservoir reaches a predetermined pressure, closing the third valve and controllably opening the second valve to dose the ammonia-containing hydrolysis gas from the reservoir into the exhaust gas.

36 The method according to claim 35 wherein, in step c), the third valve opens once the pressure in the reactor exceeds a predetermined pressure in excess of 10 bar.

37 The method according to claim 36 wherein, in step c), the third valve opens once the pressure in the reactor exceeds a predetermined pressure in the range of 10 to 16 bar.

38 The method according to claim 35 wherein, in step d), the first valve opens once the pressure in the reactor exceeds a second set pressure in the range 12-18 bar.

39 The method according to claim 38 wherein, in step d), the first valve opens once the pressure in the reactor exceeds a second set pressure in the in the range 14-17 bar.

40 The method according to claim 35 wherein in step e) the apparatus starts to dose from the reservoir once the pressure therein reaches a predetermined pressure in the range of 4-8 bar,

41 The method according to any one of claims 35 to 40 wherein, following step e) the method further comprises the step of,

f) when the pressure within the reservoir falls below a predetermined pressure, closing the second valve and opening the third valve such that ammonia is dosed directly from the reaction vessel into the exhaust, bypassing the reservoir;

g) simultaneously, above a predetermined pressure within the reaction vessel, allowing the first valve to open and any excess gaseous hydrolysis produce to escape from the reaction vessel into the reservoir via said first valve thereby causing the pressure within the reservoir to rise; and

g) once the pressure within the reservoir reaches a predetermined pressure, closing the third valve and controllably opening the second valve to dose the ammonia-containing hydrolysis gas from the reservoir into the exhaust system of the IC engine to flow with the exhaust gas through the SCR catalyst.

42 The method according to claim 41 wherein the predetermined pressure in step f) and g) is in the range of 4-8 bar.

43 The method according to any one of claims 35 to 42 wherein, in times of peak demand for ammonia-containing hydrolysis product, both the second and the third valves open simultaneously.

44 A method of controlling the output flow rate, through a pressure control valve, of a thermo-hydrolysis reactor for producing ammonia-containing gas by heating an aqueous solution of urea or the like contained in the lower section thereof, the reactor adapted to be placed in the exhaust conduit of an IC engine such that, in use, heat transmitted through the walls of the reactor from exhaust gas passing through the exhaust conduit heats the solution therein causing it to hydrolyse producing said ammonia-containing gas, the method comprising the steps of:

a) measuring the temperature of the exhaust gas; and

b) increasing or decreasing the pressure of the ammonia-containing gas within the reactor to control the temperature of the aqueous solution of urea in the lower section of the reactor thereby varying the temperature difference between the aqueous solution of urea and the exhaust gas to control the rate of heat transfer into the reactor.

45 The method according to claim 44 wherein, when the demand for ammonia-containing gas decreases, the pressure control valve is operable to increase the pressure within the reactor to reduce the temperature difference between the aqueous solution of urea and the exhaust gas and therefore reduce rate of heat transfer into the reactor slowing its output.

46 The method according to claim 44 wherein, when the demand for ammonia-containing gas increases, the pressure control valve is operable to lower the pressure within the reactor to increase the temperature difference between the aqueous solution of urea and the exhaust gas and therefore increase rate of heat transfer into the reactor increasing its output.

47 The method according to Claim 44 wherein the reactor pressure is always maintained within the range 8 to 25 bar.

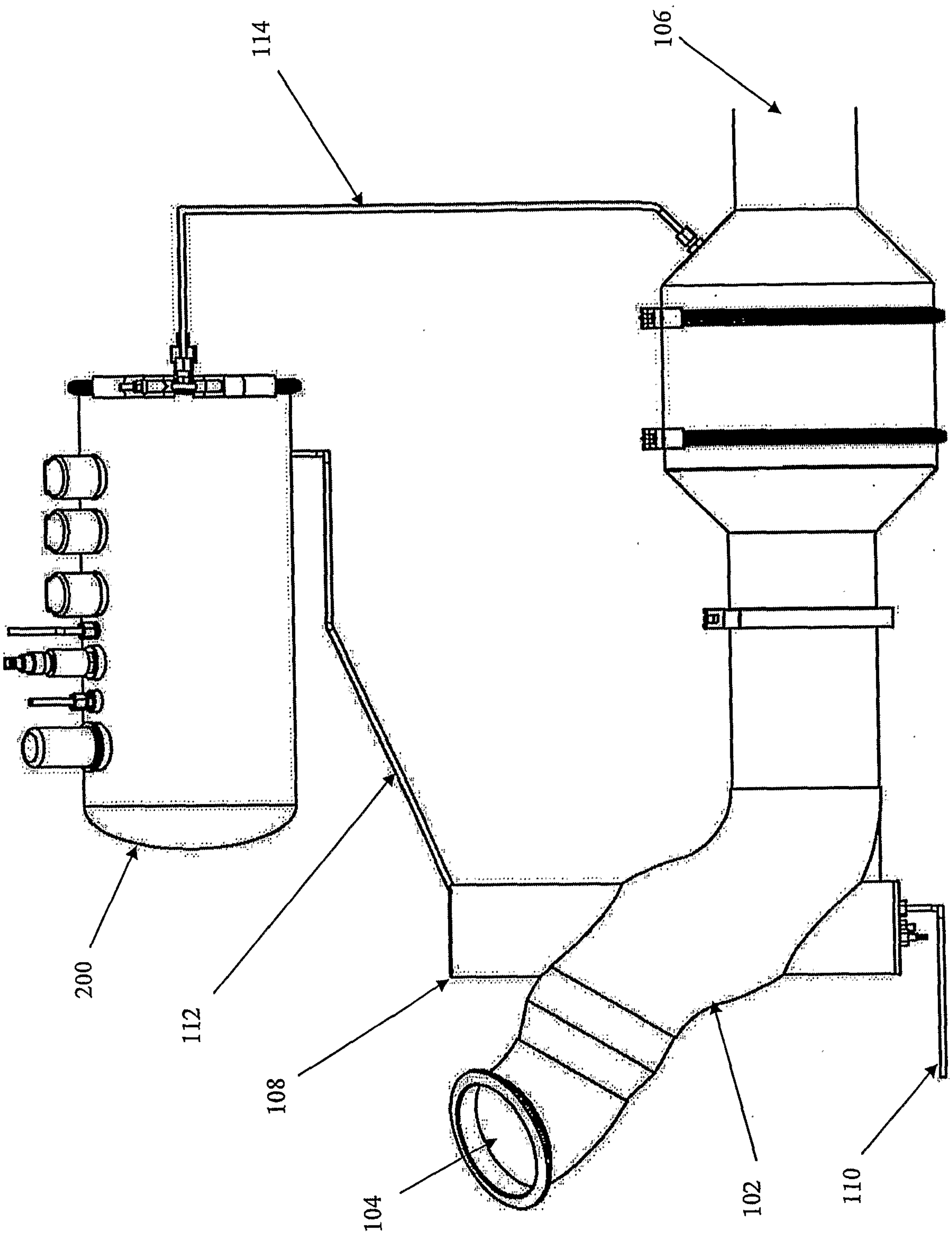


Figure 1

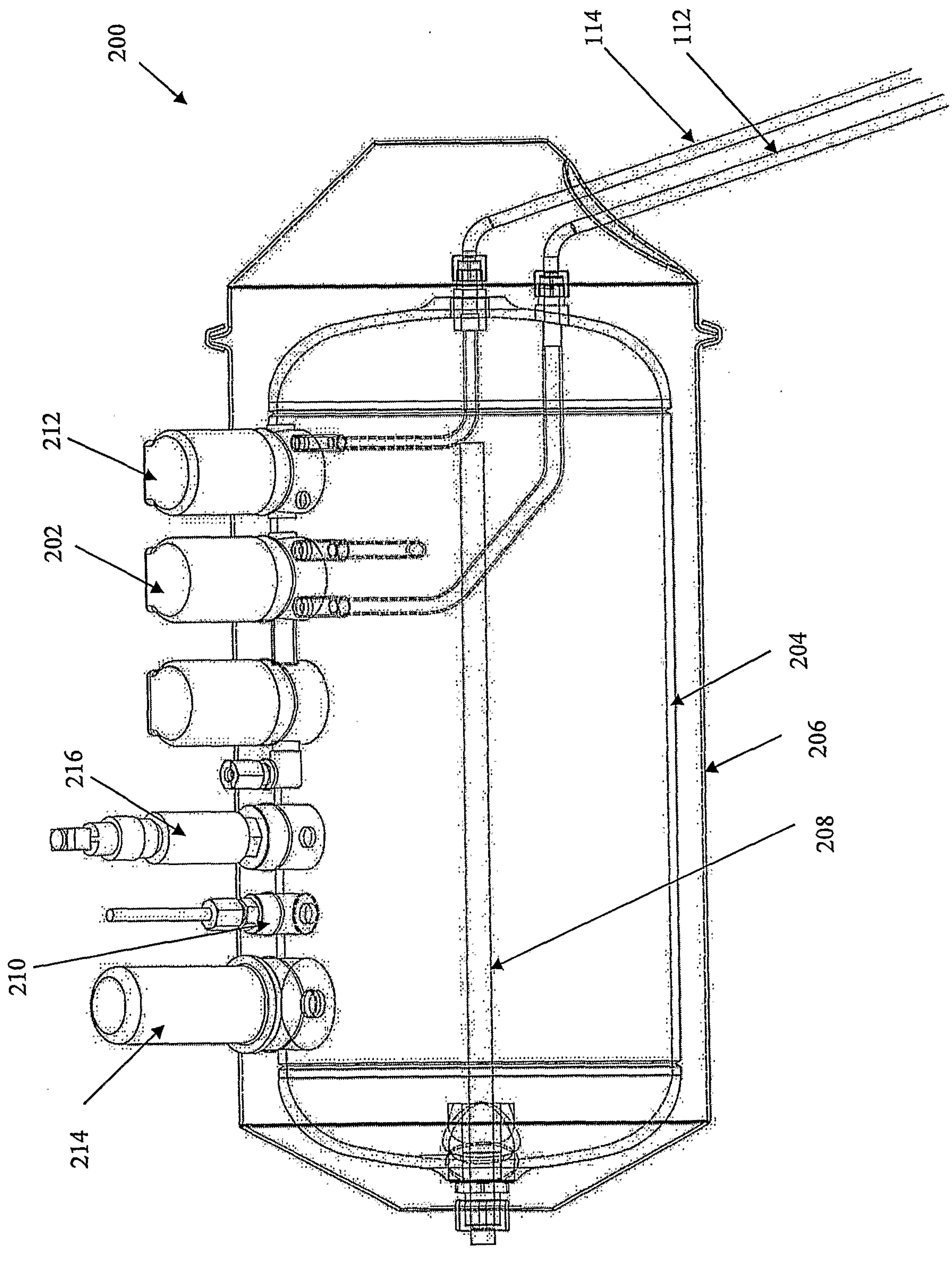


Figure 2

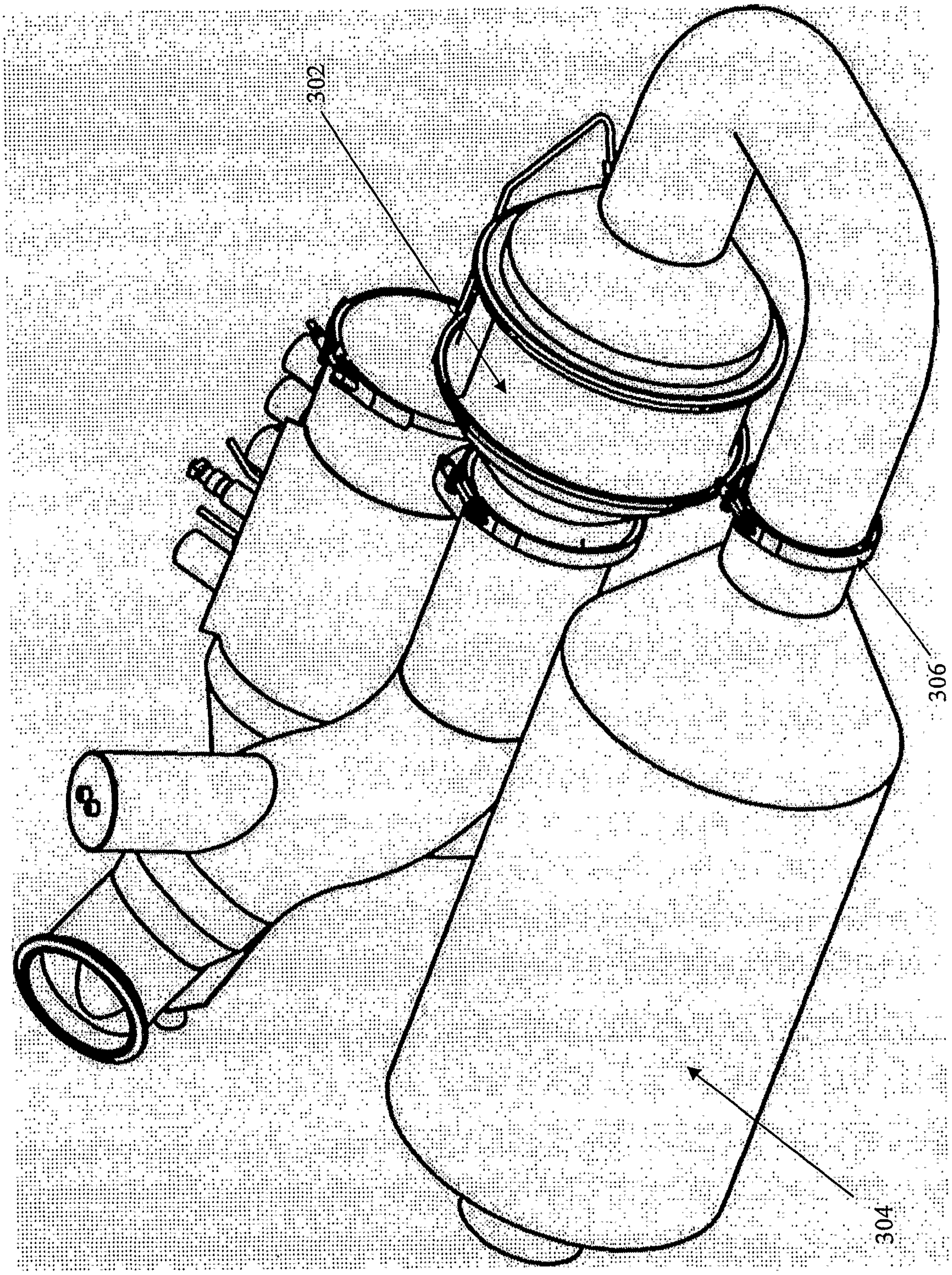


Figure 3

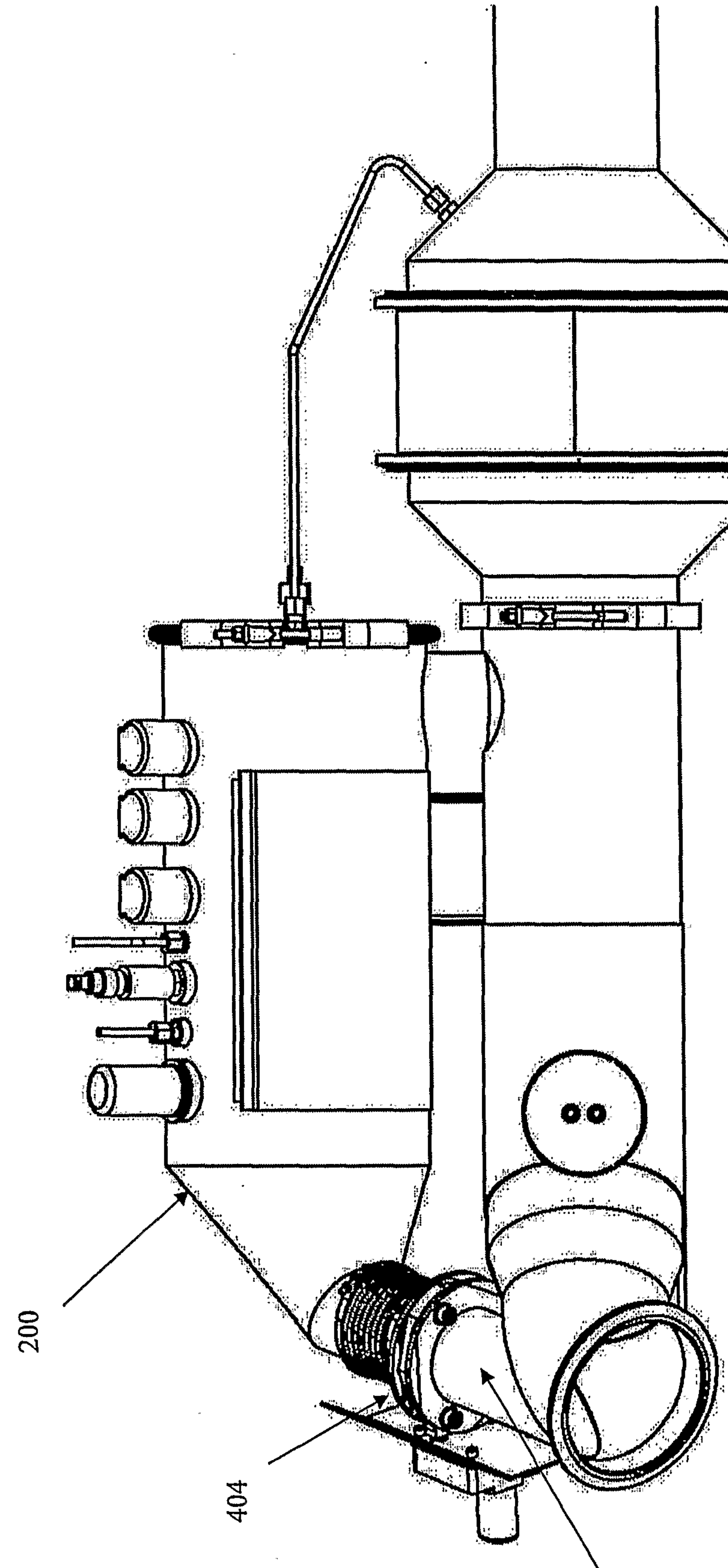


Figure 4

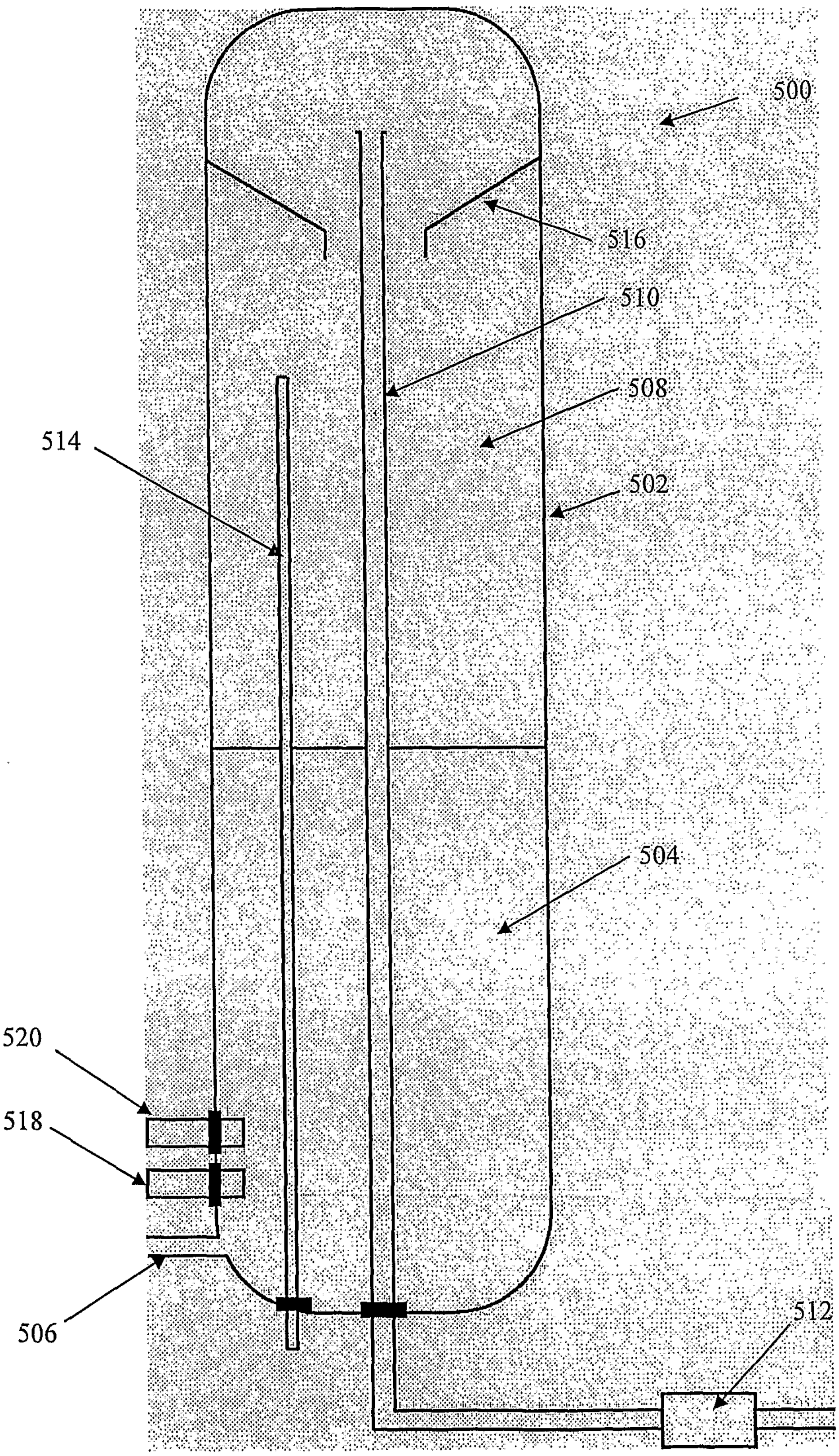


Figure 5

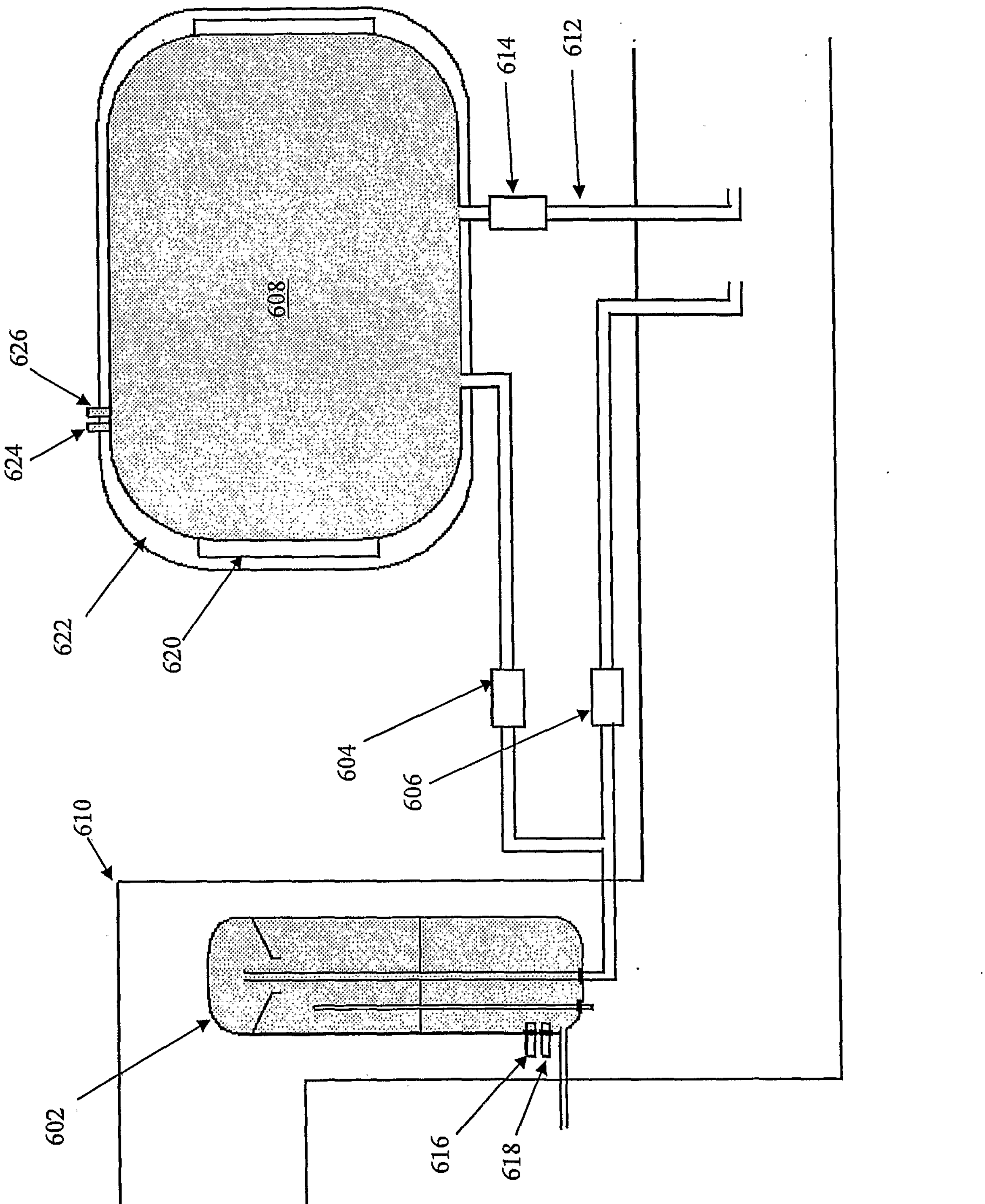


Figure 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2007/003093

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01N3/20 F01N3/28 F01N5/02 B01D53/86 B01D53/94

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F01N B01D

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 361 754 B1 (PETER-HOBLYN JEREMY D [GB] ET AL) 26 March 2002 (2002-03-26) cited in the application the whole document	1,25,31, 34,35,44
A	DE 42 00 514 A1 (ASEA BROWN BOVERI [CH]) 15 July 1993 (1993-07-15) column 2, line 45 - column 3, line 24; figures 1,2	1,31
A	EP 1 481 719 A (HITACHI LTD [JP]; HITACHI HIGH TECH CORP [JP]; BABCOCK HITACHI KK [JP]) 1 December 2004 (2004-12-01) abstract; figure 1	1

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 November 2007	27/11/2007

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Tatus, Walter

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2007/003093

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 6361754	B1	26-03-2002	NONE		
DE 4200514	A1	15-07-1993	NONE		
EP 1481719	A	01-12-2004	JP	2004353523 A	16-12-2004
			US	2005013756 A1	20-01-2005