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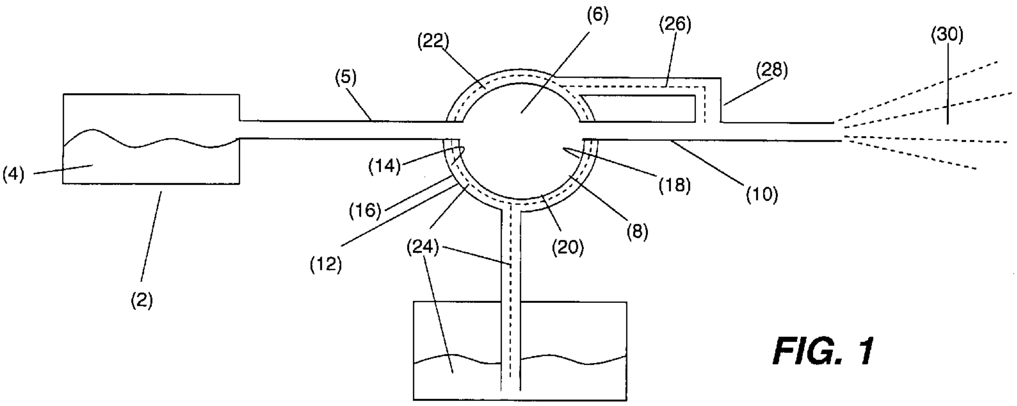

FIG. 1

(57) Abstract: The present invention relates to an apparatus, in some embodiments a hand-held apparatus, and a method for the production of steam through contacting reactants and a catalyst.

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Steam Production

The present invention relates to an apparatus, in some embodiments a hand-held apparatus, and a method for the production of steam through contacting reactants and a catalyst.

In the art, steam is generally produced using systems that boil water. If the system application requires that the temperature of the steam be greater than 100°C, the systems that boil water are also required to be pressurised. These systems require a boiler which is usually bulky and difficult to handle. Therefore, these systems could not be described as suitable for mobile operations, and especially cannot be described as hand-held.

There are a number of different applications which benefit from the use of steam and / or the heat generated by steam, for example cleaning, weed-killing, paint stripping, decontamination and melting applications, where the steam itself or the elevation of temperature generated by the steam can offer benefits.

WO 2005/075342 discloses the initiation of a reaction between methanol and a peroxide using a catalyst comprising a group 7, 8, 9, 10 or 11 transition metal starting at low temperatures.

Therefore, there is a need for improved steam generation apparatuses and improved methods of producing steam.

There is also a need for more mobile, in particular hand-held, steam generation apparatuses.

The object of the present invention is to provide an apparatus for producing steam from reactants that may react at room temperature.

A further object of the present invention is to provide an apparatus for producing steam from reactants wherein the flow rate, pressure and temperature of the reactants and steam are simple to control.

A further object of the present invention is to provide a mobile apparatus for producing steam.

A further object of the present invention is to provide a hand-held apparatus for producing steam.

A still further object of the present invention is to provide an improved method for producing steam.

The present invention provides an apparatus for the production of a product mixture comprising steam, said apparatus comprising a contacting means for bringing at least two liquid reactants into contact with a catalyst which catalyses an exothermic reaction between the at least two liquid reactants to produce the product mixture comprising steam.

The present invention further provides a method of producing a product mixture comprising steam, comprising the step of bringing at least two liquid reactants into contact with a catalyst which catalyses an exothermic reaction between the at least two liquid reactants to produce the product mixture comprising steam using the apparatus as described herein.

The present invention further provides a method of producing a product mixture comprising steam, comprising the step of bringing at least two liquid reactants into contact with a catalyst which catalyses an exothermic reaction between the at least two liquid reactants to produce the product mixture comprising steam.

The present invention also provides the use of the apparatus as described herein for the production of a product mixture comprising steam.

The product mixture comprising steam may be directed at a target, such as a surface, and used for a number of applications, such as cleaning, weed-killing, paint stripping, decontamination (e.g. killing of contaminating organisms) and melting applications.

These applications benefit from the use of steam or heat and it is highly advantageous for the steam- or heat-producing apparatus to be mobile, as described in the present application.

When the reactants are brought into contact with the catalyst, a reaction is initiated between the reactants. After the reaction is initiated, the reactants continue to react due to the heat produced since the reaction is exothermic. The product of this reaction is termed herein "the product mixture".

In one aspect, the exothermic reaction between the reactants produces steam. Alternatively, or in addition, the exothermic reaction may heat liquid water present at the site of the exothermic reaction. The liquid water undergoes a state change to produce steam. The liquid water may be present in the form of an aqueous solution of one or more of the reactants.

The contacting means of the present invention may comprise a reactant reservoir for containing the reactants and delivery means for delivering the reactants to the catalyst. The contacting means may comprise a first reactant reservoir for containing at least a first reactant, a second reactant reservoir for containing at least a second reactant and delivery means for delivering the reactants to the catalyst.

The two reservoirs may be separate from one another. This arrangement is particularly advantageous when using high concentrations of reactants for safety reasons.

The first and second reactant reservoirs may alternatively comprise separate compartments in a single body.

When the reactants are mixed together, they form a reactant mixture. The reactants may be mixed together subsequent to leaving the first and second reactant reservoirs and prior to contacting the catalyst.

As will be clear to the skilled person, the contacting means may comprise more than two reactant reservoirs with the reactants distributed between the reservoirs in any suitable manner.

Any or all of the reactant reservoirs may comprise a pressure relief system to remove any pressure from gases produced by the reactants.

Each reactant reservoir of the present invention may be made from any suitable material, which is inert to the reactants. Suitable materials include plastics material, metal and glass.

Advantageously, all or any of the reactant reservoirs are manufactured from plastic material. This is possible if the reactants are stored at a temperature below the melting point of the plastics material, preferably at room temperature, prior to the reactants being brought into contact with the catalyst. Manufacturing any of the reactant reservoirs from plastics material makes the apparatus more economical to produce, providing the possibility of the production of single use, disposable apparatuses of the present invention. Furthermore, manufacturing any of the reactant reservoirs from plastics material reduces the weight of the apparatus, which is particularly advantageous for mobile apparatuses and especially advantageous for hand-held apparatuses.

Alternatively, all or any of the reactant reservoirs may be manufactured from metal. Any metal used must be inert to the reactants. This is advantageous if the apparatus is not intended to be a single use, disposable apparatus since metal is generally more durable than plastics materials.

Preferably, the or each reactant reservoir and the catalyst are in fluid communication through one or more fluid connections to allow the reactants to pass from the or each reactant reservoir to contact the catalyst.

The fluid connection(s) between the or each reactant reservoir and the catalyst allows the reactants to pass from the or each reactant reservoir to the catalyst. Therefore, the method of the present invention may comprise the step of transferring the reactants from the or each reactant reservoir to contact the catalyst through one or more fluid connections.

Each fluid connection may comprise one or more sections.

Preferably, the one or more sections include a low thermal conductivity material. Preferably, the low thermal conductivity material is plastics material (preferably a heat resistant thermoplastic).

Preferably, a catalyst enclosure with an inner surface and an outer surface is positioned around the catalyst, as described below.

In an alternative aspect, the one or more sections may include a low thermal conductivity material (as described above) surrounding a metal material such that the metal material provides support to the one or more sections.

The low thermal conductivity material at least partially connects the or each reactant reservoir and the catalyst or catalyst enclosure. As previously discussed, a large amount of heat is generally produced during the exothermic reaction. Therefore, the catalyst is likely to become hot during the reaction. The low thermal conductivity material reduces the amount of heat transferred from the catalyst to the or each reactant reservoir and/or to the outside environment. The presence of a low thermal conductivity material is particularly advantageous if any of the reactant reservoirs are manufactured from plastics material since it prevents the plastics material from softening or melting due to the heat from the catalyst and any catalyst enclosure. The presence of a low thermal conductivity material is also advantageous if any of the reactant reservoirs are manufactured from metal since it prevents heating of these reactant reservoirs, which could result in burns to the user, and disadvantageous heating of the reactants.

Preferably, the reactants comprise a peroxide and one or more organic compounds. The peroxide employed in the present invention may be any suitable peroxide, that is hydrogen peroxides and/or organic peroxides may be employed. One or more peroxides may be present in the reactants. Examples of organic peroxides include alkyl peroxides, such as t-butyl peroxide and cumyl peroxide and peracetic acid. Benzoyl peroxide may also be used. Preferably the peroxide is hydrogen peroxide.

The hydrogen peroxide can be used in pure form, but is preferably used in solution, especially in aqueous solution or alcohol solution. The alcohol present in the alcohol solution may be methanol or ethanol, or any soluble alcohol, as long as it can form a uniform solution with peroxide aqueous solution. The alcohol is preferably methanol. Generally, the hydrogen peroxide solution comprises about 6 % or more hydrogen peroxide, preferably about 8 % or more, more preferably about 10 % or more, most preferably about 15 % or more. Advantageously, from about 20 % to about 90 %, preferably from about 20 % to about 80 %, more preferably from about 20 % to about 70 %, more preferably from about 20 % to about 50 %, more preferably from about 25 % to about 60 %, most preferably from about 25% to about 35% hydrogen peroxide is used.

Unless otherwise indicated, percentages, as used herein, when referring to % compositions of liquids, are % by weight.

Suitable organic compounds include substituted and unsubsubstituted hydrocarbons. The organic compound is preferably an alcohol.

The hydrocarbon may be substituted with one or more substituents. The one or more substituents are preferably electronegative heteroanions. Suitable substituted hydrocarbons include alcohols, carboxylic acids, aldehydes, ketones, esters, ethers or combinations thereof.

Suitable alcohols include mono-alcohols and polyols. Suitable mono-alcohols include methanol, ethanol, propanol (including n-propanol or i-propanol), butanol and pentanol or a mixture of them, preferably methanol. Suitable polyols include ethylene glycol and glycerols. Preferably the alcohol is methanol.

The reactants preferably are methanol and hydrogen peroxide.

Preferably the molar ratio of peroxide to organic compound at the catalyst is from about 10:1 to about 1:10, preferably from about 4:1 to about 1:4, preferably from about 3:1 to about 1:3. In one aspect of the present invention, the peroxide and organic compound are present in a molar ratio of from about 4:1 to about 3:1, preferably about 3:1. When hydrogen peroxide and methanol are employed, the hydrogen peroxide and methanol are preferably present in a molar ratio of from about 10:1 to about 2:1, more preferably from about 4:1 to about 3:1, most preferably from about 3.5:1 to about 3:1.

Preferably, the liquid reactants comprise water, *i.e.* each liquid reactant is an aqueous solution of at least one reactant. Preferably, water makes up about 90% or less, preferably 80 % or less, preferably 70 % or less, more preferably 60 % or less of the reactant mixture.

Preferably, the reactants are at a temperature of less than about 40°C, preferably less than about 27°C, more preferably less than about 25°C, most preferably about room temperature (or ambient temperature).

The liquid reactants may additionally comprise one or more stabilisers to stabilise the liquid reactants, especially to stablise the H_2O_2 solution. Preferred stabilisers are selected from phosphate and stanate.

Preferably, the delivery means is a means for passing the reactants across the catalyst. Any suitable means may be used to cause the reactants to pass across the catalyst.

In one aspect of the present invention, the delivery means for passing the reactants across the catalyst comprises one or more pumps, in which case the reactants are pumped across the catalyst by the pump(s).

Each pump may be any suitable pump known to the skilled person, *e.g.* a mechanical pump or an electric pump.

If an electrical pump is used, it is preferable that the electrical pump is a battery powered electrical pump. However, electrical pumps powered by any means would be suitable.

The apparatus may comprise a pump for each reactant reservoir such that the reactants may be pumped across the catalyst. In one aspect, all the pumps provided in the apparatus are mechanical pumps. In an alternative aspect, all the pumps provided in the apparatus are electrical pumps. In a further alternative aspect, the pumps provided in the apparatus may be a mixture of mechanical and electrical pumps.

If a pump is used, it is preferable that the pump is operated by a trigger action. Advantageously, the trigger action is achieved by a trigger operated by the user's hand. In use, therefore, the user preferably operates the apparatus with a single hand. The apparatus is positioned in the required position, a certain distance from a target. The trigger is operated by one or more of the user's fingers depressing the trigger to bring the reactants into contact with the catalyst, thereby producing the product mixture which may undergo further steps (as discussed herein) to form the final product mixture. The product mixture, or the final product mixture, leaves the apparatus as a gaseous stream and is applied to a target.

Operation of the pump by the user's hand is particularly advantageous for use in apparatuses of the present invention which are mobile, particularly those which are hand-held. Operation of the pump, in a mobile apparatus, by the user's hand means the apparatus does not require connection to a power supply. This is advantageous, especially if the power supply is heavy or of fixed position (e.g. mains power supply) since these types of power supply would reduce the mobility of the apparatus. Operation of the pump by the user's hand in a mobile apparatus allows the user to transport the apparatus to the required location and trigger the pump to cause the reactants to pass across the catalyst and initiate the reaction.

In one aspect, all or any of the reactant reservoirs may be manufactured from plastics material and the delivery means used to cause the reactants to pass across the catalyst may be squeezing the reactant reservoir(s), possibly manually.

In a further aspect of the present invention, the delivery means causing the reactants to pass across the catalyst may be the action of a pressurised gas. Preferably the pressurised gas is provided by a gas cylinder. Preferably the gas is nitrogen and the gas cylinder is a nitrogen cylinder. Preferably, the pressurised gas causes the reactants to pass across the catalyst with a substantially even flow rate (as herein defined).

Preferably, the gas cylinder is in fluid communication with the or each reactant reservoir such that the reactants are under a pressure of at least about 5,000Pa, preferably at least about 10,000Pa, more preferably at least about 20,000Pa. Preferably, the reactants are under a pressure of about 120,000 Pa or less, preferably about 50,000 Pa or less. The catalyst is under a lower pressure than the pressurised reactants such that the pressurised reactants are brought into contact with the catalyst, preferably through the fluid connection between the or each reactant reservoir and the catalyst.

In a still further aspect of the present invention, the delivery means may be gravity. Therefore, in this aspect, the or each reactant reservoir is located above the catalyst, such that gravity will bring the reactants into contact with the catalyst. Preferably, gravity acts to enable the reactants to pass through the fluid connection between the or each elevated reactant reservoir and the catalyst. In this aspect, it is preferable that gravity causes the reactants to pass across the catalyst with a substantially even flow rate (as herein defined).

Hereinafter, the trigger action and manual squeezing embodiments will be termed the "manual" embodiments. All other embodiments, *e.g.* non-trigger activated mechanical pumps and electrical pumps, pressurised gas or gravity, will be termed "non-manual" embodiments.

In combination with the suitable delivery means to cause the reactants to pass across the catalyst, particularly, but not exclusively, those described above, a valve may be provided to control the amount of the reactants brought into contact with the catalyst.

Preferably, the valve is located in the fluid connection between the or each reactant reservoir and the catalyst. The valve may be used to restrict the volume of the reactants passing across the catalyst or to stop the passage of the reactants across the catalyst completely.

Therefore, the method of the present invention may comprise the restriction of the volume of the reactants passing across the catalyst.

Preferably, the valve comprises a one way valve or a control valve and a one-way valve. This ensures that steam from the reaction cannot pass back into the or each reactant reservoir.

In the non-manual embodiments, it is preferable that the reactants pass across the catalyst with a substantially even flow rate. Preferably, a "substantially even flow rate", as used herein, refers to an instantaneous flow rate which is within ±10 % of the average flow rate.

Preferably, in the non-manual embodiments, the average flow rate of the reactants is about 0.001 ml/min or above, preferably from about 0.001 ml/min to about 1000ml/min, more preferably from about 0.1 ml/min to about 500ml/min, still more preferably from about 5 ml/min to about 250 ml/min, still more preferably from about 10 ml/min to about 100 ml/min, still more preferably from about 20 ml/min to about 70 ml/min.

A substantially even flow rate advantageously achieves a more even distribution of the reactants on the part of the catalyst over which the reactants are passing than a more variable flow rate would. This ensures that the reaction has a higher yield in comparison to a reaction initiated under the same conditions but with a more variable flow rate.

Preferably, in the manual embodiments, the average flow rate of the reactants is about 0.001 ml/min or above, preferably from about 0.001 ml/min to about 100ml/min, more preferably from about 0.1 ml/min to about 80ml/min, still more preferably from about 5 ml/min to about 80 ml/min, still more preferably from about 10 ml/min to about 80 ml/min, still more preferably from about 20 ml/min to about 70 ml/min.

In all embodiments, the liquid hourly space velocity of the reactants across the catalyst is from about 100 h^{-1} to about 10,000 h^{-1}, preferably from about 500 h^{-1} to about 5000 h^{-1}, preferably from about 1000 h^{-1} to about 2000 h^{-1} preferably about 1800 h^{-1}. The liquid hourly space velocity is calculated using the volume feed of the reactants divided by the volume of the catalyst. A liquid hourly space velocity that is too high may lead to the catalyst being overwhelmed with the reactants which may in turn lead to flooding and/or poisoning of the catalyst. A liquid hourly space velocity that is too low may lead to the apparatus producing less steam than is required for the application.

In all embodiments of the present invention, it is preferable that the catalyst used in the present invention is any solid catalyst which is able to catalyse the reaction of the reactants to produce the product mixture comprising steam. Preferably the catalyst is a solid transition metal or noble metal catalyst that is able to catalyse the reaction of the reactants to produce the product mixture comprising steam. Preferably the catalyst is one of those described in WO 2007/015070 or WO 2005/075342.

Catalysts suitable for use in the present invention can be prepared using any method known in the art. The preparation methods include wet impregnation, incipient wetness impregnation, ion-exchange, mechanical mixing and sol-gel methods. The preferred methods are ion-exchange or incipient wetness impregnation.

Preferably, the catalyst active components comprise precious metals and/or transition metals which may be Pt, Pd, Rh, Ir, Ru, Ni, Os, Re, Co, Fe, Mn, Cu, Ag, Au, or combinations thereof. Preferably, the active catalyst component is Pt which may be used alone or may be promoted by any main group metal, non-metal, transition metal compound or combinations thereof. It is preferred that the active compound is used in the reduced state. To increase the catalyst activity and stability, a catalyst promoter may also be used. This can be transition metal such as nickel or cobalt.

The catalyst of the present invention may be supported. The support can be any stable inert support, such as alumina, modified alumina, silica, a molecular sieve, such as zeolite Y, silicon carbide or any inert material composite. Preferably, the support is alumina, and may be gamma-alumina, theta-alumina or alpha-alumina. In order to increase the stability of the support, the support may be modified using other compounds. Typical modifiers include rare earth metal compounds or non-metal compounds, such as phosphate.

In one aspect of the present invention, the catalyst used is x%Pt-y%Pd/[z%CZY-t%Al_2O_3-La_2O_3 doped]. In this catalyst, CZY stands for cerium-zirconia stabilised by yttria having the composition a%CeO_2-b%ZrO_2-c%Y_2O_3. All the percentages of the catalyst compositions are in w/w. The catalyst may have the values:

x% and y% may independently be from 0.001% to 10%, preferably from 0.1% to 8%, preferably from 0.1% to 5% of the total weight of the catalyst,

z% may be from 30% to 70%, preferably 40%; and

t% may be from 70% to 30%, preferably 60%;

wherein z% and t% add up to 100%.

CZY may have the values:

a% may be 1% to 60%, preferably 20% to 60%, preferably 30% to 60%, preferably 40% to 60%, preferably 40% to 50%, preferably 50%;

b% may be 1% to 60%, preferably 20% to 60%, preferably 30% to 60%, preferably 40% to 60%, preferably 40% to 50%, preferably 46%; and

c% may be 1% to 10%, preferably 1% to 8%, preferably 1% to 6%, preferably 4%;

wherein a%, b% and c% add up to 100%

The catalyst of this aspect may be 3%Pt-1%Pd/[50%CZY-50%Al_2O_3-La_2O_3 doped] wherein CZY is 50%CeO_2-46%ZrO_2-4%Y_2O_3.

The catalyst of this aspect is able to generate steam having a temperature of from 100°C to 300°C using the method and apparatus of the present invention. When generating steam at low temperatures, it may not be necessary to cool the catalyst.

The catalyst of this aspect may be used with reactants which comprise hydrogen peroxide at 50 % or less, preferably 30 % or less, and methanol at from 5 % to 20 %, preferably 5 to 15 %, and water at 60 % or more. The conversion of the reactants using this formulation is high since reaction selectivity is maximised.

The ability to use dilute reactants improves the safety of the steam production by reducing the explosive and/or flammable behaviour of the reactants. Furthermore, diluting the reactants reduces the temperature of the catalyst (*e.g.* reducing hot spots). High temperatures at the catalyst can result in deactivation of the catalyst after a short time, due to support collapse and metal sintering. Therefore, diluting the reactants increases the lifetime of the catalyst (time before deactivation caused by high temperatures).

Without wishing to be bound by theory, the inventors believe that the catalyst of this aspect reduces support collapse and metal sintering in the following way. The high thermal and mechanical stability of the support inhibits collapse of the porous structure of the support due to support phase transformation while the reaction is proceeding. The CeO_2 provides a strong metal-support interaction and has a specific surface area close to 100 m^2/g, making this material suitable to prepare highly dispersed noble metal catalysts (as nanoparticles). This property may decrease the rate of the metal sintering compared to more conventional catalyst supports such as γ-alumina. Therefore, the mixed oxide support used in the catalyst of this aspect helps to lower the overall deactivation rate of the catalyst. In addition, the active material based on CeO_2-ZrO_2-Y_2O_3 solid solution exhibits oxidising/reducing properties (oxygen storage capacity). Such material is likely to generate additional active sites at the metal-support interface available for oxidation. This function increases the amount of oxygen available to the metallic active phase, thus reinforcing the catalytic activity. This property limits the formation of incompletely oxidized compounds. As a consequence, a high selectivity towards carbon dioxide and water is obtained during the reaction and the level of possible by-products such as carbon monoxide, methane, ethane and hydrogen is reduced.

Furthermore, and again without wishing to be bound by theory, Pd and Pt are highly active metals in oxidation catalysis. Moreover, Pd is more resistant towards sintering than Pt at high temperatures under oxidizing conditions. The Pd and Pt of the catalyst of this aspect can form an alloy at high temperatures, generating a more stable metallic phase and additional active catalytic sites for oxidation, which in turn reinforce the catalytic activity.

The catalyst of this aspect may be manufactured by depositing a noble metal Pt-Pd phase on the mixed oxide of cerium, zirconium and rare earth-stabilized (yttrium) on a support of gamma-alumina doped with lanthanum.

Preferably, a catalyst enclosure with an inner surface and an outer surface is positioned around the catalyst (this arrangement may also be referred to as a reactor). The catalyst enclosure may be manufactured from any suitable material that is able to withstand any heat produced during the reaction. Preferably, the catalyst enclosure is made from metal, preferably thin-walled, heat-conducting metal. The catalyst enclosure may be any suitable size or shape. The catalyst enclosure may be a circular, square or rectangular tube shape.

Therefore, the method of the present invention may comprise the step of passing the reactants through a catalyst enclosure.

The catalyst may be secured in the catalyst enclosure by any suitable means. Preferably, the catalyst is secured in the catalyst enclosure by a first and a second porous member, which may be retaining screens. The first porous member is positioned at a first end, *i.e.* upstream, of the catalyst enclosure proximal to the or each reactant reservoir. The second porous member is positioned at a second end, *i.e.* downstream, of the catalyst enclosure distal to the or each reactant reservoir.

The first retaining porous member maintains in place the catalyst but allows the reactants to pass through substantially unimpeded to contact the catalyst. The first retaining porous member has liquid porosity. The first retaining porous member may be a liquid distributor.

The apparatus may additionally comprise a means for ensuring uniform flow of the reactants over the catalyst. This means may be provided by the first retaining porous member, which may be a liquid distributor, although it may also be provided by any other suitable means. This reduces channelling in the catalyst which may lead to localised increased catalyst temperatures and hot spots, discussed above.

The second porous member maintains in place the catalyst but allows the product mixture to pass through substantially unimpeded. The second porous member has at least gaseous porosity.

The first and second porous members may be retaining screens or gauzes, manufactured from any suitable material. Preferably, the first and second porous members are manufactured from a material that is able to withstand any heat produced during the reaction. Preferably, the first and second porous members are made from metal, preferably stainless steel.

Therefore, the method of the present invention may comprise the steps of passing the reactants through a first porous member, contacting the reactants with the catalyst within the catalyst enclosure to produce the product mixture and allowing the product mixture to pass through a second porous member.

The catalyst may be located within the catalyst enclosure in any suitable configuration.

In an aspect of the present invention, the catalyst is in the form of an impregnated tube reactor. In an impregnated tube reactor, the catalyst is impregnated onto the inner surface of a tube, which may be the inner catalyst enclosure.

In another aspect of the present invention, a fixed bed reactor may be used. A fixed bed reactor may comprise a catalyst coated onto a monolith. The monolith may be divided into a number of channels with inner surfaces coated with the catalyst. The reactants pass through the channels in the monolith and are brought into contact with the catalyst coated onto the inner surfaces of the channels.

The monolith may be manufactured from any suitable material that is able to withstand any heat produced during the reaction. Preferably, the monolith is manufactured from stainless steel, ceramics, aluminium, copper, or any strong alloy. The monolith can be any suitable size, shape or configuration. The monolith can be held in place within the catalyst enclosure by supports.

The catalyst may be coated onto any surface within the catalyst enclosure. The coating technique may be any suitable technique known in the art, e.g. wash-coating or screen printing.

Alternatively, the fixed bed reactor may comprise particles of catalyst and optionally a diluent. The diluent is preferably an inert material, e.g. quartz particles, quartz wool, silicon carbide, boron carbide, alumina or silica. The diluent disperses some of the heat generated by the reaction. The ratio of catalyst to diluent is preferably at most 20:1, preferably from about 1:1 to about 1:20, more preferably from about 1:4 to about 1:8. Preferably, the catalyst particles and the diluent are held in position inside the catalyst enclosure by the first and second porous members. Preferably, the catalyst and diluent particles are the same size to avoid leaching and channelling in the fixed bed reactor. Preferably, the reactants pass through the first porous member and into the catalyst enclosure where they are brought into contact with the catalyst.

Alternatively, one or more fixed bed reactors may be used in combination as in a shell and tube reactor. This type of reactor consists of a shell, which may be the catalyst enclosure, with one or more tubes inside. The tubes may run the length of the shell from the first porous member to the second porous member, or may be U-shaped such that they enter and exit the shell at the first porous or the second porous member.

In one aspect, the tubes comprise the catalyst such that the catalyst is present in the form of one or more catalyst tubes, either cylindrical or another suitable shape, which preferably are positioned co-axially within the catalyst enclosure. The catalyst tubes may be held in place by any suitable method, including supports within the catalyst enclosure. The catalyst tubes are positioned such that there is space between them through which, in one aspect, the reactants may pass or, in an alternative aspect, catalyst cooling fluid may pass while the reactants pass through the catalyst tubes. In other words, in this alternative aspect the cooling fluid passes through the shell and the reactants pass through the tubes which contain the catalyst.

In an alternative aspect, the shell may contain the catalyst through which the reactants pass while the cooling fluid passes through the tubes, such that one or more cooling tubes are positioned through the catalyst. Preferably, the one or more cooling tubes are positioned through the catalyst, preferably from the first porous member to the second porous member. The one or more cooling tubes are manufactured from a material that is able to withstand any heat produced during the reaction. Preferably, the one or more cooling tubes are made from metal.

Preferably, there is provided a means for allowing a catalyst cooling fluid to pass through the one or more cooling tubes or the shell of the reactor. Preferably the catalyst cooling fluid is cool or cold such that, as it passes through the one or more cooling tubes, it conducts heat away from the catalyst.

Shell and tube reactors may be particularly advantageous for steam production for industrial applications, *i.e.* where larger quantities of steam are required. When producing large quantities of steam, it is necessary to have an efficient catalyst cooling system, which may be provided by a shell and tube reactor. This reduces the problem of localised heating of the catalyst when using higher concentrations of reactants. For safety reasons, when using high concentrations of reactants, the reactants may be stored separately in more than one reactant reservoir and mixed just prior to use.

Where it is critical to either keep the catalyst temperature low or create a very compact design, a plate or multi-channel heat exchanger reactor is preferable. This is an alternative type of fixed-bed reactor. Typically, these systems are made of corrugated, sequentially-layered plates that when diffusion welded or pressed together form tubes that can hold two fluids in very close proximity. This enables very high heat transfer rates. In this system, every other layer is coated with the catalyst. When the reactants are pumped to the catalyst containing channels, the product mixture is generated. Excessive heat is taken away by the cooling fluid contained in the alternate channels. The channels may be microchannels, meaning that they have a diameter of from 1 mm to 5 mm, preferably from 1 mm to 2 mm.

The method of the present invention may comprise the step of cooling the catalyst. Preferably, the catalyst is cooled by allowing a catalyst cooling fluid to pass around and/or through the catalyst.

In one aspect of the present invention, a cooling enclosure with an inner surface and an outer surface may be positioned around the catalyst enclosure. Since the reaction is exothermic, as discussed above, a large amount of heat is produced during the reaction. Therefore, the catalyst and any catalyst enclosure present will become hot during the reaction.

A cooling enclosure advantageously encloses and cools the catalyst enclosure and hence the catalyst. If the cooling enclosure were not provided, the catalyst enclosure may be exposed on the surface of the apparatus. This increases the risk of burns to the user of the apparatus, particularly if the apparatus is a hand-held apparatus. Furthermore, the cooling enclosure provides a means for conducting heat away from the catalyst enclosure, and hence from the catalyst, increasing the lifetime of the catalyst.

Preferably, there is a space between the inner surface of the cooling enclosure and the outer surface of the catalyst enclosure. Preferably, there is provided a means for allowing the catalyst cooling fluid to pass through the space between the inner surface of the cooling enclosure and the outer surface of the catalyst enclosure. Preferably the catalyst cooling fluid is cool or cold such that, as it passes through the space between the inner surface of the cooling enclosure and the outer surface of the catalyst enclosure, it conducts heat away from the catalyst enclosure.

In a still further aspect of the present invention, the catalyst may be cooled by one or more cooling fins positioned through the catalyst. The one or more cooling fins may have passages through them such that the catalyst cooling fluid may be passed through them. The one of more cooling fins may be any shape having a high surface to volume ratio such that when the catalyst cooling fluid is passed through the cooling fins, the catalyst is efficiently cooled.

Alternatively, there may be provided a cooling enclosure and/or one or more cooling tubes and/or one or more cooling fins as described herein.

A catalyst cooling fluid reservoir may be provided for containing the catalyst cooling fluid. Preferably, the catalyst cooling fluid reservoir is in fluid communication with the space between the inner surface of the cooling enclosure and the outer surface of the catalyst enclosure and/or the one or more cooling tubes and/or the one or more cooling fins by a second fluid connection such that the catalyst cooling fluid can pass from the catalyst cooling fluid reservoir to cool the catalyst.

Any suitable means may be used to allow the catalyst cooling fluid to pass from the catalyst cooling fluid reservoir to cool the catalyst, e.g. a pump (including mechanical and electrical), pressurised gas or gravity.

The apparatus of the present invention may additionally comprise a guard bed. The guard bed may be positioned upstream of the catalyst such that the reactants pass through the guard bed before contacting the catalyst. Alternatively, the guard bed may be integral with the catalyst. The guard bed removes impurities, such as the one or more stabilisers, from the reactants to reduce poisoning of the catalyst and thereby increase the catalyst lifetime.

The guard bed may be anything suitable for removing impurities from the reactants, *e.g.* an ion exchange resin, a zeolite, alumina or a Ni catalyst.

The product mixture comprises steam. The product mixture may further comprise carbon dioxide (CO_2), a trace amount of methane and/or a trace amount of carbon monoxide. Preferably, the product mixture comprises from about 50 % (w/w) to about 90 % (w/w), preferably about 67 % (w/w) to about 85 % (w/w), water (in the form of steam). Preferably, the product mixture comprises from about 50 %(w/w) to about 10 % (w/w), preferably about 33 % (w/w) to about 15 % (w/w), CO_2. Preferably, the product mixture comprises only water (in the form of steam) and CO_2.

In the non-manual embodiments, the steam generated by the contact between the reactants and the catalyst may have a temperature of from about 200°C to about 900°C, preferably from about 300°C to about 800°C, preferably from about 400 °C to about 750°C, preferably from about 400 °C to about 500°C.

In the manual embodiments, the steam generated by the contact between the reactants and the catalyst may have a temperature of from about 150 °C to about 450°C, preferably from about 200 °C to about 400°C.

The contact between the reactants and the catalyst may generate steam at different temperatures depending on the % wt composition of the at least two reactants, *e.g.* an aqueous solution containing 31 wt% hydrogen peroxide / 9 wt% methanol produces steam at a temperature of 350-420°C, depending on the reactor configuration and insulation.

The apparatus of the present invention may comprise a means for mixing an additive with the product mixture to form a final product mixture.

The additive may be liquid or gaseous and is preferably gaseous. Suitable additives are non–flammable and/or non-dangerous and/or thermally stable.

The additive may have a temperature lower than that of the product mixture. Any additive with a temperature lower than that of the product mixture will cool the product mixture. The additive may also be tailored to benefit the end use of the steam. Therefore, the additive may comprise water, or a compound which is desirable for cleaning, weed-killing, paint stripping, fragrancing, decontamination or melting purposes. Preferably, each of the catalyst cooling fluid and the additive comprises or consists essentially of water.

The additive may comprise a cleaning fluid. Therefore, when the product mixture is mixed with the additive (or the recycled catalyst cooling fluid), the cleaning fluid will be present in the final product mixture. This is particularly advantageous if the apparatus is to be used for cleaning purposes.

Suitable cleaning fluids include diluted detergents and degreasing agents preferably with a high water content.

Although the steam generated by the contact between the reactants and the catalyst may be an effective weed-killer alone, it is possible to also provide an additive which comprises a weed-killing fluid. Therefore, when the product mixture is mixed with the additive (or the recycled catalyst cooling fluid), the weed-killing fluid will be present in the final product mixture. This is particularly advantageous if the apparatus is to be used for weed-killing purposes. The weed-killing fluid may be any suitable weed-killing fluid known in the art.

The method of the present invention may comprise the step of cooling the product mixture. In one aspect of the present invention, the product mixture is cooled by allowing it to mix with an additive at a lower temperature than the product mixture.

In a further aspect, the method of the present invention may comprise the step of enhancing the product mixture by allowing it to mix with a cleaning fluid additive.

In a still further aspect, the method of the present invention may comprise the step of enhancing the product mixture by allowing it to mix with a weed-killing additive.

In a still further aspect, the method of the present invention may comprise the step of enhancing the product mixture by allowing it to mix with a fragrancing additive.

The apparatus may comprise an additive chamber fluidly connected to an additive reservoir which contains an additive. Preferably, the additive chamber is positioned downstream of the catalyst such that the product mixture passes through the additive chamber and is mixed with the additive. Preferably, the additive chamber is adjacent, and downstream of, the catalyst. The additive reservoir may be made from any suitable material, e.g. plastics material, metal or glass.

Generally, the additive will cool the product mixture. Therefore the additive chamber may be termed a cooling chamber which is fluidly connected to an additive reservoir for containing the additive. Preferably, the cooling chamber is positioned downstream of the catalyst such that the product mixture passes through the cooling chamber and is cooled. Preferably, the cooling chamber is adjacent, and downstream of, the catalyst. The additive reservoir may be made from any suitable material, e.g. plastics material, metal or glass.

Preferably, there is provided a means for allowing the additive to pass to the additive chamber and mix with the product mixture passing therethrough. Therefore, the composition which passes out of the additive chamber comprises a mixture of the product mixture and the additive. This composition is known herein as the “final product mixture”.

The means for allowing the additive to pass to the additive chamber and mix with the product mixture passing therethrough may be the Venturi effect.

The volume and temperature of additive mixed with the product mixture per second will determine the temperature of the final product mixture, such that a higher volume of additive per second and/or a lower temperature of additive will lead to a cooler final product mixture than lower volume of additive per second and/or a lower temperature of additive. This is advantageous as it allows the product mixture to be cooled to a usable temperature and allows the temperature of the final product mixture to be tailored to the application.

In the non-manual embodiments, the final product mixture may be at a temperature of from about 50°C to about 800°C, preferably from about 200°C to about 500°C, preferably from about 200°C to about 300°C.

In the manual embodiments, it is preferable that the final product mixture is at a temperature of from about 50°C to about 250°C, preferably from about 80°C to about 200°C, preferably from about 100°C to about 250°C, preferably from about 150°C to about 200°C. A product mixture or final product mixture of under 200°C is preferable because it is visible to the human eye. This is advantageous for safety reasons to avoid burns to the user. Alternatively, the final product mixture may be made visible to the human eye by mixing it with the additive which may be recycled catalyst cooling fluid. Preferably the additive, *e.g.* the recycled catalyst cooling fluid, includes steam, which is likely not to be superheated (like the steam in the product mixture) and will therefore contain water droplets which will make the final product mixture visible to the human eye.

Advantageously, in any embodiment of the present invention, the catalyst cooling fluid may be used as the additive after the step of cooling the catalyst (*i.e.* the additive is recycled catalyst cooling fluid). Therefore, there may be provided a means for mixing the exiting catalyst cooling fluid with the product mixture to provide the final product mixture. This means may be provided in addition to the provision of a cooling chamber fluidly connected to an additive reservoir for containing an additive as described herein. Preferably, the means for mixing the exiting catalyst cooling fluid with the product mixture to provide the final product mixture is a third fluid connection providing fluid communication between the space between the inner surface of the cooling enclosure and the outer surface of the catalyst enclosure and/or the one or more cooling tubes with the product mixture through which the recycled catalyst cooling fluid may pass.

Generally, when the catalyst cooling fluid is cooling the catalyst, it undergoes a change of state from liquid to vapour. The vapour produced from the catalyst cooling fluid is at a lower temperature than the product mixture, as discussed above. Preferably, the temperature of the vapour produced from the catalyst cooling fluid is about 200 °C or less, more preferably about 150 °C or less, most preferably about 100 °C. When the vapour from the catalyst cooling fluid is mixed with the product mixture (*i.e.* the additive is recycled catalyst cooling fluid), the product mixture may be cooled to a desired temperature.

As discussed previously, the additive, which may be recycled catalyst cooling fluid, may comprise water, or a compound which is suitable for cleaning, weed-killing, paint stripping, fragrancing, decontamination or melting purposes. Preferably, each of the catalyst cooling fluid and the additive comprises or consists essentially of water.

On mixing the additive with the product mixture, the additive may cool the product mixture to form the final product mixture. In one aspect, if a large amount of additive is mixed with the product mixture, the final product mixture may be in the form of a hot liquid. This hot liquid may be ejected from the device by residual CO_2 from the product mixture. In an alternative aspect, if a small amount of additive is mixed with the product mixture, the final product mixture may be in gaseous form comprising the vapours of the additive. This aspect is particularly advantageous in fragrancing applications where the fragrance vapours are desirable to fragrance, for example, a room. In this aspect, the additive is preferably volatile and may be a fragrance and/or an essential oil. The additive may be contained in a porous wick which may be in the flow of the product mixture. The product mixture may pass over the porous wick producing a final product mixture that contains the additive.

It is especially advantageous for the catalyst cooling fluid to comprise or consist essentially of water when the additive is recycled catalyst cooling fluid. While cooling the catalyst, the water in the catalyst cooling fluid heats up and changes state to become a vapour which comprises steam. Therefore, when the steam from the catalyst cooling fluid is mixed with the product mixture, the product mixture may be cooled to a desired temperature. Furthermore, the steam from the catalyst cooling fluid adds to the steam present in the product mixture, producing a final product mixture having an increased volume of steam. This is a beneficial use of the heat produced by the process of the present invention to increase the volume of steam generated.

Any additive to the product mixture which comprises water will advantageously increase the volume of steam in the final product mixture.

In a further aspect, the product mixture may be cooled by providing a long passage through which the product mixture must pass subsequent to the catalyst and prior to exiting the apparatus. The outside of this passage is surrounded by gas, preferably air, preferably the outside atmosphere, which cools the product mixture. The gas surrounding the passage may be cooled by a cooling means. The length of the passage must be sufficient to cool the product mixture to a usable temperature, preferably from about 50°C to about 800°C, preferably from about 200°C to about 500°C, preferably from about 200°C to about 300°C in the non-manual embodiments or from about 50°C to about 250°C, preferably from about 80°C to about 200°C, preferably from about 100°C to about 250°C, preferably from about 150°C to about 200°C in the manual embodiments.

The method of the present invention may comprise the step of allowing the product mixture to expand. Therefore, the apparatus may comprise an expansion nozzle. The expansion nozzle is located downstream of the catalyst, preferably adjacent the additive chamber. Most preferably, the product mixture (or the final product mixture if the product mixture has been mixed with the additive) leaves the apparatus through the expansion nozzle. The product mixture (or the final product mixture) is generally gaseous and preferably leaves the expansion nozzle in the form of a gaseous stream. The expansion nozzle allows the gaseous stream to expand such that, when the apparatus is positioned the required distance from a target, the gaseous stream covers a larger area of the target than would be possible at that required distance without the expansion nozzle. This is advantageous since the target may be covered more quickly with the gaseous stream. If the apparatus is used for cleaning purposes, the expansion nozzle therefore allows the target to be cleaned more quickly.

Alternatively, the pressure of the gaseous stream may be increased by restricting the area from which the gaseous stream leaves the apparatus. The restriction of the area from which the gaseous stream leaves the apparatus may be achieved through the use of a restriction nozzle located downstream of the catalyst, preferably adjacent the additive chamber. The gaseous stream leaves the apparatus through the restriction nozzle.

In a further aspect, the pressure of the gaseous stream may be increased through the use of a valve (e.g. a needle valve) through which the product mixture or final product mixture must pass before exiting the apparatus.

Advantageously, the pressure of the gaseous stream may be increased to about 600 kPa or greater, more preferably about 700 kPa or greater, most preferably about 8 kPa.

The use of varying sizes of expansion and restriction nozzles (*i.e.* varying the area through which the gaseous stream leaves the apparatus) allows the skilled person to tailor the velocity of the gaseous stream to suit the application.

Preferably, the means for bringing the reactants into contact with the catalyst comprises one or more tubes, which are advantageously capillary tubes. Therefore, the method of the present invention may comprise the step of allowing the reactants to pass through one or more capillary tube(s).

Each capillary tube may be manufactured from any suitable material and is preferably manufactured from a material that can withstand any heat produced during the reaction. Preferably, each capillary tube is manufactured from a low thermal conductivity material, as described above. Advantageously, when a capillary tube is manufactured from a low thermal conductivity material, it reduces the heat transferred from the catalyst, which is hot due to the reaction, to the reactant reservoir. This is particularly advantageous if the reactant reservoir is manufactured from plastics material since it prevents the reactant reservoir melting. However, this is also advantageous if the reactant reservoir is manufactured from metal since it prevents heating of the reactant reservoir, which could result in burns to the user, and disadvantageous heating of the reactants.

Each capillary tube advantageously reduces wetting of the catalyst with water, reduces the liquid inventory, restricts passage of the reactants to the catalyst and reduces back pass from the catalyst to the reactant reservoir.

This is advantageous since, if the catalyst is wet with water, it is unable to catalyse the reaction since the catalyst is effectively shielded by the water. The lower the inventory on the liquid side of the catalyst, the lower the chance that wetting will occur.

Advantageously, the catalyst remains hot subsequent to the reaction. Any liquid remaining on the catalyst subsequent to the reaction may therefore boil off, leaving the catalyst dry for the next reaction.

Alternatively or in addition to the provision of capillary tubes, the apparatus may comprise a means of draining any water from the catalyst to reduce wetting. This may be achieved by locating the catalyst in a position such that, when the apparatus is in use, the fluid connection, preferably the capillary, between the reactant reservoir and the catalyst is vertical (*i.e.* in the same direction as the force of gravity) such that the force of gravity reduces wetting of the catalyst. In this aspect of the present invention, it is preferable that the product mixture (or the final product mixture) leaves the apparatus horizontally (*i.e.* perpendicular to the fluid connection between the reactant reservoir and the catalyst, preferably perpendicular to the capillary).

Alternatively or in addition, the catalyst may comprise inner and outer catalyst sections to reduce wetting. In this aspect, the outer catalyst section at least partially surrounds the inner catalyst section. The apparatus of this aspect also comprises a switch such that the user can select whether to pass the reactants across the inner catalyst section or the outer catalyst section. Passing the reactants through the outer catalyst section will produce heat which will heat the inner catalyst section, evaporating any residual water and drying the inner catalyst section. In the same way, passing the reactants through the inner catalyst section will produce heat which will heat the outer catalyst section, evaporating any residual water and drying the outer catalyst section. The switch can be used to alternate the catalyst sections used, thereby increasing the operating time of the apparatus before wetting prevents any further steam from being produced.

Subsequent to the reaction, the catalyst is preferably dried. In one aspect of the present invention, gas (preferably air) may be passed over the catalyst subsequent to the reaction to dry the catalyst.

The apparatus of the present invention is preferably mobile (and hence suitable for mobile operations). As used herein, the term “mobile” refers to an apparatus which can be moved, preferably by a single user, to a position wherein it can be used to produce the product mixture comprising steam.

In one aspect, a mobile apparatus of the present invention may comprise a back pack which includes the reactant reservoir(s) and any cooling fluid reservoir with the remainder of the apparatus being hand-held (according to the definition provided below). Preferably, the back pack is a suitable weight to be carried on the user’s back, preferably less than 14 kg, preferably less than 10 kg, more preferably less than 7.5 kg, more preferably about 5 kg.

In an alternative aspect of the present invention, the mobile apparatus may comprise the reactant reservoir(s) and any cooling fluid reservoir which are adapted to be carried on a trolley, with the remainder of the apparatus being hand-held (according to the definition provided below).

In a further aspect of the present invention, the mobile apparatus may be hand-held. As used herein, a "hand-held" apparatus is easily liftable and portable by a single user using only one hand. Preferably, a "hand-held" apparatus of the present invention can be lifted and moved easily by the user with one hand. A hand-held apparatus of the present invention, containing its maximum capacity of reactants and cooling fluid, preferably weighs about 2000 g or less, preferably from about 100 g to about 1000 g, preferably from about 100 g to about 500 g, more preferably from about 120 g to about 350 g.

The present invention also provides an apparatus substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

The steam produced by the apparatus and/or method of the present invention may be used for any application in which steam is required. In one aspect, the steam may be used in power generation, for example in driving a turbine. In a further aspect, the steam may be used to generate electricity. These aspects are particularly applicable to the non-manual embodiments discussed herein.

The steam in the product mixture or final product mixture generated using the method and/or apparatus of the present invention can be used for generating electricity for instance to replace batteries. The reactant reservoir(s) of this aspect preferably contain from 50 to 10,000 litres, more preferably from 100 to 5,000 litres, most preferably from 1,000 to 2,000 litres of reactants. The means for contacting the reactants and the catalyst may comprise a small mechanical or electrical pump such as a dosing pump. The pump is preferably a high pressure pump (2,100 kPa) since this type of pump is a cost effective way to raise the pressure of the product mixture using a small amount of energy. The product mixture or final product mixture is delivered to a steam engine, which is preferably a turbine device and more preferably an expander. The steam in the product mixture or final product mixture turns the turbine which in turn drives an electrical generator. Advantageously, since the method and/or apparatus of the present invention generates steam in the form of the product mixture or the final product mixture rapidly, this system can begin generating electricity within 10 seconds.

The steam in the product mixture or final product mixture, generated by the method and/or apparatus of the present invention, may be used to power a car. A car powered by this means would not require a boiler. Therefore, the weight of the car is reduced and a faster start up is possible. The reactant reservoir(s) of this aspect preferably contain from 50 to 500 litres, more preferably from 60 to 250 litres, most preferably from 70 to 200 litres of reactants. The reactants are pumped via a control valve to one or more turbines. These turbines preferably have the catalyst closely mounted to the turbine inlet so that the product mixture or final product mixture is generated only when it is required. These turbines preferably are mounted in the hubs of the wheels of the car or closely coupled to a conventional gearbox. The control valve is preferably operated by the accelerator that the driver can modulate the flow of the reactants to the turbines, thereby increasing or decreasing the power output. Advantageously, a car run in this way gives off no NO_X or SO_X, but produces only water and a small amount of CO_2.

The steam generation of the present invention also produces heat, which can be used in any application in which heat is required, for example heating food and/or liquids and/or body parts. This may be particularly advantageous for camping applications.

In one aspect, some of the heat generated is used to heat the catalyst cooling fluid. When the catalyst cooling fluid comprises water, this produces steam which may be mixed with the product mixture, when the additive is recycled catalyst cooling fluid. This is described above.

The present invention is now described, by way of illustration only, with reference to the accompanying drawings, in which:

Figure 1 shows an apparatus according to the present invention;
Figure 2 shows a hand-held apparatus according to the present invention;
Figure 3 is an enlarged view of the catalyst enclosure;

Figure 4 is an enlarged view of the additive chamber;

Figure 5 shows a hand-held apparatus according to the present invention adapted to reduce wetting;

Figure 6 shows the one or more cooling tubes;

Figure 7 shows a cooling enclosure;

Figure 8 shows catalyst bed and steam outlet temperature as a function of time of steam and dry gas phase composition after steam condensation for 3%Pt-1%Pd/[50%CZY-50%Al_2O_3-La_2O_3 doped];

Figure 9 shows conversion, selectivity and dry gas composition as a function of time for 3%Pt-1%Pd/[50%CZY-50%Al_2O_3-La_2O_3 doped]; and

Figure 10 shows the deactivation profile for 3%Pt-1%Pd/[50%CZY-50%Al_2O_3-La_2O_3 doped] as a function of time.

An apparatus according to the present invention is shown diagrammatically in Figure 1. The apparatus comprises a reactant reservoir (2) containing the reactants (4). A catalyst (6) is provided inside a catalyst enclosure (8). The reactant reservoir (2) and the catalyst (6) are in fluid communication via a fluid connection (5) to allow the reactants (4) to pass from the reactant reservoir (2) to contact the catalyst (6) and produce a product mixture (10) comprising steam.

A cooling enclosure (12) is provided with an inner surface (14) and an outer surface (16). The cooling enclosure (12) is positioned around the catalyst enclosure (8). The catalyst enclosure (8) has an inner surface (18) and an outer surface (20).

There is a space (22) between the inner surface (14) of the cooling enclosure (12) and the outer surface (20) of the catalyst enclosure (8). A catalyst cooling fluid (24) passes through the space (22) between the inner surface (14) of the cooling enclosure (12) and the outer surface (20) of the catalyst enclosure. The catalyst cooling fluid (24) is cool or cold such that, as it passes through the space (22) between the inner surface (14) of the cooling enclosure (12) and the outer surface (20) of the catalyst enclosure (8), it conducts heat away from the outer surface (20) of the catalyst enclosure (8).

The catalyst cooling fluid (24) is also used as an additive (26) after it has cooled the catalyst (6) (*i.e.* the additive (26) is recycled catalyst cooling fluid (24)). Therefore, the catalyst cooling fluid (24) from the space (22) between the inner surface (14) of the cooling enclosure (12) and the outer surface (20) of the catalyst enclosure (8) passes through a fluid connection (28) between the space (22) between the inner surface (14) of the cooling enclosure (12) and the outer surface (20) of the catalyst enclosure (8) and mixes with the product mixture (10) to form the final product mixture (30).

A hand-held apparatus according to the present invention is shown in Figure 2. The hand-held apparatus comprises a reactant reservoir (2) manufactured from plastic material. The reactant reservoir (2) contains the reactants (4). A catalyst (6) is provided inside a catalyst enclosure (8). The reactant reservoir (2) and the catalyst (6) are fluidly connected to allow the reactants (4) to pass from the reactant reservoir (2) to contact the catalyst (6). The fluid connection consists of a section of low thermal conductivity material (32) and a capillary tube (34).

The reactants are pumped across the catalyst by a mechanical pump (36) operated by a trigger (38). The trigger is operated by the user's hand (40) in a trigger action. The user holds and operates the apparatus with a single hand. The apparatus is positioned in the required position, a certain distance from a target (42). The mechanical pump (36) is operated by two of the user's fingers depressing the trigger (38) in a trigger action to bring the reactants (4) into contact with the catalyst (6), producing product mixture.

An additive chamber (44) is provided in fluid communication by a fluid connection (46) to an additive reservoir (48) containing an additive (50). The additive (50) is mixed with the product mixture in the additive chamber (44) to produce the final product mixture (30).

An expansion nozzle (52) is provided located downstream of the catalyst (6) and adjacent the additive chamber (44). The final product mixture (30) leaves the apparatus through the expansion nozzle (52) in a gaseous stream.

Figure 3 shows in more detail the catalyst enclosure of Figure 2. The catalyst enclosure (8) is positioned around the catalyst (6). The catalyst (6) is in the form of a fixed bed reactor. The catalyst enclosure (8) has an inner surface (18) and an outer surface (20).

The catalyst (6) is secured into the catalyst enclosure (8) by a first porous member (54) and a second porous member (56). The first porous member is positioned at the first end of the catalyst enclosure (8) proximal to the reservoir. The second porous member is positioned at the second end of the catalyst enclosure distal to the reservoir. The direction of passage of the reactants (4) and the direction of passage of the product mixture (10) are shown in this figure.

Figure 4 shows in more detail the additive chamber of Figure 2. The additive chamber (44) is shows with the fluid connection (46) to the additive reservoir (not shown). The additive (50) passes out of the fluid connection and mixes with the product mixture (10) to produce the final product mixture (30).

Figure 5 shows an alternative arrangement for a hand-held apparatus according to the present invention. The hand-held apparatus of Figure 5 is adapted to reduce wetting of the catalyst (6). A reactant reservoir (2) is provided manufactured from plastics material. The reactant reservoir (2) contains the reactants (4). The catalyst (6) is provided inside the catalyst enclosure (8). The reactant reservoir (2) and the catalyst (6) are in fluid communication via a fluid connection to allow the reactants (4) to pass from the reactant reservoir (2) to contact the catalyst (6). The fluid connection consists of a section of low thermal conductivity material (32) and a capillary tube (34).

Wetting of the catalyst (6) is reduced by locating the catalyst (6) in a position such that the capillary tube (34) is vertical and the force of gravity reduces wetting of the catalyst. The final product mixture (30) leaves the apparatus horizontally (*i.e.* perpendicular to the capillary tube (34)).

The reactants are pumped across the catalyst by a mechanical pump (36) operated by a trigger (38). The trigger is operated by the user's hand (40) in a trigger action. The user holds and operates the apparatus with a single hand. The apparatus is positioned in the required position, a certain distance from a target (42). The mechanical pump (36) is operated by two of the user's fingers depressing the trigger (38) in a trigger action to bring the reactants (4) into contact with the catalyst (6) producing product mixture.

An additive chamber (44) is provided in fluid communication via a fluid connection (46) to an additive reservoir (48) containing an additive (50). The additive (50) is mixed with the product mixture in the additive chamber (44) to produce the final product mixture (30).

An expansion nozzle (52) is provided located downstream of the catalyst (6) and adjacent the additive chamber (44). The final product mixture (30) leaves the apparatus through the expansion nozzle (52) in a gaseous stream.

Figure 6 shows an enlarged view of the catalyst enclosure of Figure 5. The catalyst enclosure (8) contains the catalyst (6). The catalyst (6) is cooled by allowing a catalyst cooling fluid (24) through the catalyst (6). One or more cooling tubes (54) are positioned through the catalyst (6). The catalyst cooling fluid (24) passes through the one or more cooling tubes (54). The catalyst cooling fluid (24) is cool or cold such that as it passes through the one or more cooling tubes (54) it conducts heat away from the catalyst (6).

Figure 7 shows an enlarged view of the downstream end of the apparatus of Figure 5 and shows that the catalyst (6) is cooled by allowing a catalyst cooling fluid (24) to pass around the catalyst (6). A catalyst enclosure (8) is positioned around the catalyst (6). The catalyst enclosure (8) is cylindrical and has an inner surface (18) and an outer surface (20).

The catalyst (6) is secured into the catalyst enclosure (8) by a first porous member (54) and a second porous member (56). The first porous member is positioned at the first end of the catalyst enclosure (8) proximal to the reservoir. The second porous member is positioned at the second end of the catalyst enclosure (8) distal to the reservoir. The reactants (4) and the product mixture (10) are shown in this figure.

A cooling enclosure (12) is provided with an inner surface (14) and an outer surface (16). The cooling enclosure (12) is positioned around the catalyst enclosure (8). There is a space (22) between the inner surface (14) of the cooling enclosure and the outer surface (20) of the catalyst enclosure (8). The catalyst cooling fluid (24) passes through the space (22) between the inner surface (14) of the cooling enclosure (12) and the outer surface (20) of the catalyst enclosure. The catalyst cooling fluid (24) is cool or cold such that as it passes through the space (22) between the inner surface (14) of the cooling enclosure (12) and the outer surface (20) of the catalyst enclosure (8) it conducts heat away from the outer surface (20) of the catalyst enclosure (8).

The catalyst cooling fluid (24) is used as the additive (26) after it has cooled the catalyst (6) (*i.e.* the additive (26) is recycled catalyst cooling fluid (24)). Therefore, the catalyst cooling fluid (24) from the space (22) between the inner surface (14) of the cooling enclosure (12) and the outer surface (20) of the catalyst enclosure (8) passes through a fluid connection (28) providing fluid communication between the space (22) between the inner surface (14) of the cooling enclosure (12) and the outer surface (20) of the catalyst enclosure (8) and mixes with the product mixture (10) to form the final product mixture (30).

The invention is further illustrated by the following examples. It will be appreciated that the examples are for illustrative purposes only and are not intended to limit the invention as described above. Modification of detail may be made without departing from the scope of the invention.

Examples

Example 1.

Pressurised nitrogen from a 20 MPa nitrogen cylinder was used to pressurize 20 litres of reactants (which included 8 litres of water), in a reactant reservoir. The reactants were under a pressure of 90 kPa. The pressurised reactants passed across the catalyst at a flow rate of 50ml/min. The catalyst bed was formed of 5 grams of catalyst and 20 grams of silicon carbide. The catalyst was held in place by first and second porous members which were stainless steel gauzes with pore sizes of 150 micro meters. Upon contact of the reactants with the catalyst, the product mixture comprising steam and CO_2 was generated at a temperature of about 600°C. The temperature of the catalyst was about 950°C. The catalyst cooling fluid, which was water, was introduced into the space between the inner surface of the cooling enclosure and the outer surface of the catalyst enclosure at a flow rate of 15ml/min to cool the catalyst. During cooling, the catalyst cooling fluid changed state from liquid to vapour (steam). The steam produced is at a temperature of about 100°C, and is combined with the product mixture to generate the final product mixture at a temperature of about 200°C. Increase of the flow rate of the catalyst cooling fluid to 25ml/min reduced the temperature to about 140°C. The pressure of the final product mixture was increased to a maximum 800 kPa by restricting its flow path using a needle valve. Upon this increase in pressure, the temperature of the steam produced from the catalyst cooling fluid changed corresponding to the saturated steam temperatures at set pressures. However, the temperature of the final product mixture remained more or less stable.

Example 2.

20ml/min of the reactants was transferred from a plastic reactant reservoir to the catalyst and passed over the catalyst. The catalyst was in the form of a fixed bed reactor comprising a single catalyst tube. The catalyst comprised 500 mg catalyst and 1 gram silicon carbide. Upon contacting the catalyst with the reactants, the product mixture was generated containing steam (85%) and CO_2 (15%). Depending on the concentration of the peroxide and the organic compound in the reactants and apparatus insulation, the temperature of the product mixture exiting the apparatus was between 500 and 800°C.

(Note: - all temperatures quoted in examples 1 and 2 are +/- 15°C due to variable heat losses, all temperatures quoted in any further examples are +/- 30°C due to variable heat losses).

Example 2a.

20ml/min of the reactants was transferred from a plastic reactant reservoir to the catalyst and passed over the catalyst. The reactants used were of lower concentration that those used in example 2. The catalyst was in the form of a fixed bed reactor comprising a single catalyst tube. The catalyst comprised 500 mg catalyst and 1 gram silicon carbide. Upon contacting the catalyst with the reactants, the product mixture was generated containing steam (85%) and CO_2 (15%). Depending on the concentration of the peroxide and the organic compound in the reactants and apparatus insulation, the temperature of the product mixture exiting the apparatus was between 200 and 800°C.

Example 3

130 mg of a catalyst of formula 3%Pt-1%Pd/[50%CZY-50%Al_2O_3-La_2O_3 doped, wherein with CZY stands for 50%CeO_2-46%ZrO_2-4%Y_2O_3 w/w, was tested under powder form (63-200 μm size) mixed with silicon carbide SiC within the weight ratio SiC/catalyst = 8/1 w/w. The catalyst was arranged in a fixed bed reactor (down-flow), continuous flow system, and the reactor was kept well insulated.

The fuel composition used was 29.5%H_2O_2/8.42%CH_3OH/62.4%H_2O within a molar ratio H_2O_2/CH_3OH 3.3/1, in order to reach a theoretical steam temperature of 263°C.

The fuel flow rate was gradually decreased from 5 mL/min down to 1.8 mL/min in order to keep an optimal level of conversion at all times as the catalyst deactivates to reach a pseudo steady state.

As shown in Figure 8, a 260-300°C steam temperature range was achieved for 180 h without any external cooling system. The catalyst bed temperature was below 500°C throughout this time. An air blow through the catalyst bed was used to remove water and unreacted organic molecules from the catalyst bed between each 7-8 hours run.

As shown in Figure 9, the conversion level achieved for this catalyst was in the range of 95%-97%, corresponding to an estimated level of 0.06% CH_3OH release in gas phase (dry gas basis). A stable carbon monoxide CO level has been obtained below 0.4% on a dry gas basis. Ppm levels of hydrogen and methane, ethane were also produced as measured through Gas Chromatography analysis. The oxygen level was close to 16% dry gas basis.

The lifetime of the catalyst obtained was 140 h for 100 mg in these conditions according to the deactivation profile shown in Figure 10. The catalyst reached a pseudo steady state after 100 h.

Example 4 – Preparation of 50%CZY/50%γ-Al_2O_3-La_2O_3 doped supports made using co-precipitation

The modifiers' precursor solution composition is: CeO_2 = 50% w/w, ZrO_2 = 46% w/w, Y_2O_3 = 4% w/w.

To dope the modifiers onto Al_2O_3–La_2O_3, 6.31 g $Ce(NO_3)_3.6H_2O$ was mixed with 6.33 g $ZrO(NO_3)_2.xH_2O$ and 0.68 g $Y(NO_3)_3.xH_2O$ and the mixture was dissolved in 100ml of water. The mixture was stirred for 2 hours at room temperature to produce a colourless, acidic solution. 5 g of Al_2O_3–La_2O_3 was added to the solution under vigorous stirring and a white suspension was obtained. 2 mol/L NH_3 basic solution was added to this white solution to induce precipitation. During precipitation, stirring may be carried out manually if necessary as the viscosity of the solution is increasing. When equilibrium was reached, the pH was adjusted to pH=8 to ensure complete precipitation of the mixed oxide on the Al_2O_3-La_2O_3 support. A viscous orange slurry was obtained which was stirred for 30 min to produce a homogeneous solid. The solid was filtered under vacuum for several hours and then dried at 100°C and calcined at 700°C in air for 5 hours.

Example 5 – Preparation of 16.7%CZY/83.3%γ-Al_2O_3-La_2O_3 doped supports

A mixture containing 1.28g $Ce(NO_3)_3.6H_2O$, 1.31g $ZrO(NO_3)_2.6H_2O$ and 0.14 g $Y(NO_3)_3.6H_2O$ was dissolved in 17 ml deionised water as described in example 4. After stirring for 2 hours at room temperature a colourless, acidic solution was obtained. 8.5 mL of this solution was added dropwise to 5 g of the Al_2O_3–La_2O_3 support, following the impregnation wetness procedure. The support was then filtered, dried and calcined under the same conditions as described in example 4. The steps described in this example were then repeated to produce the final amount of CZY on the Al_2O_3-La_2O_3 support.

Example 6 – Preparation of Al_2O_3 supported 4wt% Pt (Catalyst 1)

5 g of γ-Al_2O_3 support with a specific surface area of approximately 200 m^2/g and a porous volume of approximately 0.5 g/cm^3 was sieved using a 200-355 μm mesh and then mixed with a $Pt(NH_3)_4(NO_3)_2$ impregnation solution containing an amount of Pt calculated to provide 4%w/w Pt^0 content in water.

The amount of solution added dropwise to the support was calculated using the support porous volume, the concentration of the impregnation solution and the desired Pt amount for the catalyst. In this case, two impregnation steps, each using 2.55 g of impregnation solution, were necessary. During each step, the support is continuously stirred to ensure homogeneous absorption of the Pt.

After each impregnation step, the impregnated support was dried in an oven overnight at 100°C. The dried sample was then calcined at 500°C for 2h in air using a 5°C/min ramp in a muffle furnace.

For higher metal loading, the impregnation, drying and calcination steps may be repeated as necessary.

Before carrying out the steam generation test, the catalyst was activated under H_2 at 500°C for 2h using a 2°C/min ramp with an intermediate drying step at 150°C for 1h in a tube furnace down-flow. A hydrogen flow rate of 2L/h/g was used with He or N_2 used to flush the material at the end of the H_2 reduction.

When preparing a Pt-Pd bimetallic catalyst, it is preferable to impregnate the support using steps as described in this example. This ensures that the Pt salt solution and the Pd salt solution are not mixed since this mixture would be unstable and precipitate. In this case, it is preferred to deposit Pd onto the support first.

Example 7 – 2%Pt0.5%Ce0.2%Co/Al_2O_3 catalyst

γ-Al_2O_3 was calcined at 500 °C for 2 hours before use. 19.4 g of the calcined γ-Al_2O_3 was added to 800 ml of deionised water in a 100 ml vessel. The mixture was stirred and the temperature raised to 60 °C at which is was maintained for 30 minutes. 1.1 g of chloroplatinic acid in 20 ml deionised water was added over 5 minutes. A solution of 0.3 g $Ce(NO_3)_3.6H_2O$ in 10 ml deionised water was then added over 10 minutes. A solution of 0.2 g $Co(NO_3)_3.6H_2O$ in 10 ml deionised water was then added over 10 minutes. This mixture was then stirred for 3 hours at 60 °C, cooled to room temperature and kept for more than 16 hours. The temperature of the mixture was then raised to 90-95°C and 2.8 g $NaHCO_3$ was added. 2.5g of 38% HCHO solution, diluted to 10 ml, was then added over 10 minutes. The mixture was stirred for 3-4 hours, cooled to room temperature and left overnight. The mixture was then filtered and washed to remove the chloride species. The chloride free filter cake was dried at 80 – 100°C until dry. The platinum and the cerium were alloyed with each other by reducing the mixture in a hydrogen flow at 1 °C/minute to 600 -700°C for 2 hours.

Example 8 – 0.4%Pt0.1%Ce0.1%Co/Al_2O_3 catalyst

γ-Al_2O_3 was calcined at 500 °C for 2 hours before use. 19.9 g of the calcined γ-Al_2O_3 was added to 800 ml of deionised water in a 1000 ml vessel. The mixture was stirred and its temperature was raised to 60 °C and maintained at this temperature for 30 minutes. 0.22 g of chloroplatinic acid in 20 ml deionised water was then added over 5 minutes. A solution of 0.06 g $Ce(NO_3)_3.6H_2O$ in 10 ml deionised water was then added over 10 minutes. A solution of 0.1 g $Co(NO_3)_3.6H_2O$ in 10 ml deionised water was then added over 10 minutes. The mixture was then stirred for 3 hours at 60°C, cooled to room temperature and kept for more than 16 hours. The temperature of this mixture was then raised to 90-95°C and 2.8 g $NaHCO_3$ was added into the mixture. 2.5g 38% HCHO solution, diluted to 10 ml, was then added over 10 minutes. The mixture was then stirred for 3-4 hours, cooled to room temperature and kept overnight. The mixture was filtered and washed to remove the chloride species. The chloride free filter cake was dried at 80 – 100°C until dry. The platinum and the cerium were alloyed with each other by reducing the mixture in a hydrogen flow at 1 °C/minute to 600 -700°C for 2 hours.

Example 9 – 3%Pt1%Ce/Al_2O_3 catalyst

γ-Al_2O_3 was calcined at 500 °C for 2 hours before use. 9.5 g of the calcined γ-Al_2O_3 was added in 160 ml of deionised water in a 500 ml vessel. 1.4 g $NaHCO_3$ was then added to the above solution. 0.84 g of chloroplatinic acid in 10 ml deionised water was then added over 5 minutes. A solution of 0.3 g $Ce(NO_3)_3.6H_2O$ in 5 ml deionised water was then added over 10 minutes. The mixture was then boiled for 2 hours. 1.1g 38% HCHO solution, diluted to 5 ml, was then added over 10 minutes. The mixture was then boiled for a futher 60 minutes, cooled to room temperature and kept overnight. The mixture was then filtered and washed to remove the chloride species. The chloride free filter cake was dried at 80 – 100°C until dry. The platinum and the cerium were alloyed with each other by reducing the mixture in a hydrogen flow at 1 °C/minute to 600 -700°C for 2 hours.

Example 10 – Catalytic tests

In order to assess the catalyst's performance under the steam generation reaction conditions in term of lifetime, activity and selectivity, small scale tests have been undertaken using various hydrogen peroxide solutions. The catalytic tests were carried out under the following reference conditions defined after a preliminary screening.

Reference conditions

- Fixed bed/down-flow/insulated reactor
- Reference catalyst: 4%Pt/γ-Al_2O_3
- Amount of catalyst: 100 mg
- Diluents nature: quartz or silicon carbide SiC, or alumina, or other inert materials within the same particle range as the catalyst.
- Dilution ratio: inert diluents to catalyst = 8:1 w/w
- Flow rate of the liquid feed: 0.1-50 mL/min, preferably 5ml/min, e.g., the liquid hourly space velocity is from 1 to 30,000h^{-1}
- Insulation of the reactor kept constant and thick such that the heat loss remains the same between tests

- The catalyst can be loaded in a single tubular reactor, where the liquid fuel mixture flow through it, or the reactor can be configured as a tube-shell type reactor, where two catalyst sections were employed. When one catalyst section is working, which gives heat, the other catalyst section will be heated up to be dried and re-activated. This kind of reactor configuration can help to keep the catalyst section in the not in-use reactor dry and active for next use.

The following examples use the reference conditions provided above and may use any of the catalysts of examples 3 to 8.

Trigger examples

Example 11 – Basic steam trigger spray

A reactant reservoir containing the reactants (750ml comprising 32% H_2O_2, 9% methanol and balance deionised water) was connected to a trigger spray pump. The trigger spray was hand or battery operated and produces a maximum of 2.5barg pressure. The reactants were pumped to contact 0.5 – 8.0g catalyst in a fixed bed reactor, thus creating steam at a temperature of from 200 to 800°C depending on the formulation of the fuel. At the point of delivery, the steam will ideally be visible for safety reasons, *i.e.* at a temperature in the region of 100 – 200°C. The steam can then be applied to a target to *e.g.* liquefy grease, kill weeds or shrink fit plastic. The average flow of the reactants was approximately 30ml/min and each pull on the trigger delivered 0.7 – 1.0g of the reactants to the catalyst.

Example 12 – Hard surfaces cleaner example A.

A trigger spray pump was connected to a reactant reservoir containing 650 ml of reactants. The reactants were pumped across 0.5 – 8g of catalyst and heat conducting solid diluent in a reactor. The trigger spray pump delivered 1.0g of reactants per pull on the trigger. The steam created was immediately funnelled into a restriction nozzle (10mm in diameter compared to the reactor diameter of 25mm). The acceleration of the steam was used to create a vacuum via a small (2mm diameter) tube protruding into the gas flow. The vacuum was sufficient to draw detergent up from a second vessel mounted in close proximity to the tube using the Venturi effect. The flow of the secondary detergent mixture is 1-20% of the flow of reactants depending on the placement and size of the tube. The formulation of the liquid and detergent are capable of remaining efficacious even at high temperatures (from + 50°C to + 100°C).

Example 13 – Hard surfaces cleaner example B

A two trigger spray pump system was provided with a reactant reservoir containing the reactants and an additive reservoir containing a detergent liquid. The reactant trigger spray pump is pulled delivering 1.0g of the reactants to 0.5 – 8.0g of catalyst per trigger pull, thus generating steam. The second trigger spray pump is pulled a measured time delay after the reactant trigger spray. The time delay allows for the mixture of the detergent dosage of 0.1g and the steam to be optimised for the consumer. The final product mixture is sprayed onto the target as a hot fine mist. The heat transfer from the product mixture to the detergent liquid means that the final product mixture, comprising the detergent, contacts the target at 50 – 90°C.

Example 14 – Hard surface cleaner example C

A two trigger spray pump system was provided with a reactant reservoir containing 200 ml of the reactants and an additive reservoir containing 500 ml of a detergent liquid. The additive trigger spray pump firstly delivers approximately 1.0g of the detergent to an additive chamber. Within this chamber is minimal ullage for vapour. Secondly, the reactant trigger pump delivers a dose of the reactants to the catalyst generating 0.3g of steam which is injected into the detergent liquid. The steam immediately condenses in the relatively cold detergent increasing the temperature of the liquid detergent which is ejected by the residue CO_2 in the final product mixture towards the target.

Example 15 – Full vaporisation

A trigger spray pump system was provided with a reactant reservoir containing 200 ml of the reactants. The trigger pump delivered a dose of the reactants to the catalyst generating 0.3g of steam in a product mixture. This product mixture passes over a porous wick containing fragrance. A final product mixture was produced comprising a small amount of the fragrance and was used to fragrance a room.

Energy generation examples

Example 16 – Electrical energy

A reactant reservoir of 2000 litres was used containing 1900 litres of reactants. A 20barg electrical pump was used to contact the reactants and the catalyst. The product mixture was delivered to a turbine device which drove an electrical generator. Approximately 20kW of heat energy created 4.5kW of electrical energy, equating to a flow of 400ml/min of steam from the product mixture.

Example 17 – Motive energy

A reactant reservoir of 180 litres containing 160 litres of reactants was used. The reactants were pumped via a control valve to two turbines. These turbines had the catalyst mounted within 5 cm of the turbine inlet. The control valve was operated by an accelerator driver. This system gave off no NO_X or SO_X, producing only water and only less than 15wt% of CO_2. The power output of this system was 35kW.

Reactor design examples

Example 18 – Shell and tube reactor

A shell and tube reactor 30cm long by 10 cm diameter and containing 100g of catalyst in 18 tubes of 1cm diameter was used with a reactant concentration of 40% H_2O_2 and 12% methanol.

Example 19 – Plate or multi-channel heat exchanger reactors

A reactor having channels of 1mm diameter in a 0.25m x 0.25m x 0.25m block was used with high strength reactants of 50% H_2O_2 and 15% methanol. The reactants were mixed just prior to contact with the catalyst. The catalyst loading was 3kg.

Claims

1. An apparatus for the production of a product mixture comprising steam, said apparatus comprising a contacting means for bringing at least two liquid reactants into contact with a catalyst which catalyses an exothermic reaction between the at least two liquid reactants to produce the product mixture comprising steam.

2. The apparatus according to claim 1, wherein the contacting means comprises a reactant reservoir for containing the at least two liquid reactants and delivery means for delivering the aqueous solution to the catalyst.

3. The apparatus according to claim 1, wherein the contacting means comprises a first reactant reservoir for containing at least the first liquid reactant, a second reactant reservoir for containing at least the second liquid reactant and delivery means for delivering the liquid reactants to the catalyst.

4. The apparatus according to claim 3, wherein the first and second reactant reservoirs comprise separated compartments in a single body.

5. The apparatus according to any one of claims 1 to 4, wherein the reactants comprise a peroxide and an organic compound.

6. The apparatus according to claim 5, wherein the peroxide is hydrogen peroxide.

7. The apparatus according to claim 5 or claim 6, wherein the organic compound is an alcohol.

8. The apparatus according to claim 7, wherein the alcohol is methanol.

9. The apparatus according to claim 8, wherein the peroxide is hydrogen peroxide and wherein the molar ratio of hydrogen peroxide to methanol, when the liquid reactants contact the catalyst, is from about 10:1 to about 3:1.

10. The apparatus according to any one of claims 1 to 9, wherein the delivery means is a means for passing the reactants across the catalyst.

11. The apparatus according to claim 10, wherein the delivery means comprises one or more pumps.

12. The apparatus according to claim 11, wherein at least one pump is a mechanical pump.

13. The apparatus according to claim 11 or claim 12, wherein at least one pump is an electrical pump.

14. The apparatus according to any one of claims 11 to 13, wherein each pump is operated by a trigger action.

15. The apparatus according to claim 10, wherein the delivery means comprises squeezing the reactant reservoir(s).

16. The apparatus according to claim 10, wherein the delivery means is a pressurised gas.

17. The apparatus according to claim 16, wherein the pressurised gas is provided by a gas cylinder.

18. The apparatus according to claim 16 or claim 17, wherein the gas is nitrogen.

19. The apparatus according to claim 10, wherein the delivery means is gravity.

20. The apparatus according to any one of claims 15 to 19, comprising a valve to control the amount of the reactants brought into contact with the catalyst.

21. The apparatus according to claim 20, wherein the valve comprises a one-way valve or a control valve and a one-way valve.

22. The apparatus according to any one of claims 10 to 13 and 16 to 21, additionally comprising a means for ensuring uniform flow of the reactants over the catalyst.

23. The apparatus according to any one of claims 10 to 13 and 16 to 22, wherein the means for passing the reactants across the catalyst causes the reactants to pass across the catalyst with a substantially even flow rate.

24. The apparatus according to claim 23, wherein a substantially even flow rate is an instantaneous flow rate which is within ±10% of the average flow rate.

25. The apparatus according to claim 24, wherein the liquid hourly space velocity of the reactants is from about 100 h^{-1} to about 10,000 h^{-1}.

26. The apparatus according to any one of the preceding claims, wherein the catalyst is solid.

27. The apparatus according to claim 26, wherein the catalyst is of the formula $x\%Pt\text{-}y\%Pd/[z\%CZY\text{-}t\%Al_2O_3\text{-}La_2O_3$ doped].

28. The apparatus according to any one of the preceding claims, comprising a catalyst enclosure positioned around the catalyst.

29. The apparatus according to claim 28, comprising a cooling enclosure positioned around the catalyst enclosure.

30. The apparatus according to claim 29, comprising a means for allowing a catalyst cooling fluid to pass through the space between the catalyst enclosure and the cooling enclosure.

31. The apparatus according to any one of claims 28 to 30, wherein the catalyst enclosure is cylindrical, square or rectangular tube shape.

32. The apparatus according to any one of claims 28 to 31, wherein the catalyst is secured into the catalyst enclosure by a first and a second porous member.

33. The apparatus according to any one of claims 1 to 32, wherein the catalyst is in the form of an impregnated tube reactor.

34. The apparatus according to any one of claims 1 to 32, wherein the catalyst is in the form of a fixed bed reactor.

35. The apparatus according to claim 34, wherein the catalyst is in the form of a shell and tube reactor.

36. The apparatus according to claim 35, wherein the tubes contain catalyst and cooling fluid passes through the shell.

37. The apparatus according to claim 35, wherein cooling fluid passes through the tubes and the shell contains catalyst.

38. The apparatus a according to claim 34, wherein the catalyst is in the form of a microchannel reactor.

39. The apparatus according to any one of the preceding claims, additionally comprising a guard bed.

40. The apparatus according to claim 2 or claim 3 or any claim dependent thereon, wherein the or each reactant reservoir is manufactured from a material that is inert to the reactants.

41. The apparatus according to claim 40, wherein the or each reactant reservoir is manufactured from plastic material.

42. The apparatus according to claim 40, wherein the or each reactant reservoir is manufactured from metal.

43. The apparatus according to any one of the preceding claims, comprising a means for mixing an additive with the product mixture.

44. The apparatus according to claim 43, comprising an additive chamber fluidly connected to an additive reservoir containing the additive.

45. The apparatus according to claim 43 or claim 44, wherein the additive is recycled catalyst cooling fluid.

46. The apparatus according to any one of claims 43 to 45, wherein the additive comprises steam.

47. The apparatus according to any one of claims 43 to 46, wherein the additive comprises a cleaning fluid, such as a common detergent or degreasing agent, or a fragrance.

48. The apparatus according to any one of the preceding claims, comprising an expansion nozzle.

49. The apparatus according to any one of claims 1 to 48, wherein the contacting means comprises one or more capillary tubes.

50. The apparatus according to any one of the preceding claims which is mobile.

51. The apparatus according to claim 50, which is hand-held.

52. The apparatus substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

53. Use of the apparatus of any one of claims 1 to 52 for the production of a product mixture comprising steam.

54. A method of producing a product mixture comprising steam, comprising the step of bringing at least two liquid reactants into contact with a catalyst which catalyses an exothermic reaction between the at least two liquid reactants to produce the product mixture comprising steam, using the apparatus of any one of claims 1 to 52.

55. A method of producing a product mixture comprising steam, comprising the step of bringing a solution containing at least two liquid reactants into contact with the catalyst which catalyses an exothermic reaction between the at least two liquid reactants to produce the product mixture comprising steam.

56. The method according to claim 55, wherein the reactants comprise a peroxide and an organic compound.

57. The method according to claim 56, wherein the peroxide is hydrogen peroxide.

58. The method according to claim 56 or claim 57, wherein the organic compound is an alcohol.

59. The method according to claim 58, wherein the alcohol is methanol.

60. The method according to claim 59, wherein peroxide is hydrogen peroxide and wherein the molar ratio of hydrogen peroxide to methanol, when the liquid reactants contact the catalyst, is from about 10:1 to about 3:1.

61. A method according to any one of claims 55 to 60, wherein the reactants are brought into contact with the catalyst by passing the reactants across the catalyst.

62. The method according to claim 61, wherein the reactants are pumped across the catalyst by one or more pumps.

63. The method according to claim 62, wherein at least one pump is a mechanical pump.

64. The method according to claim 62 or claim 63, wherein at least one pump is an electrical pump.

65. The method according to any one of claims 62 to 64, wherein each pump is operated by a trigger action.

66. The method according to claim 61, wherein the means for passing the reactants across the catalyst comprises manual squeezing.

67. The method according to claim 61, wherein the reactants may be caused to pass across the catalyst through the action of a pressurised gas.

68. The method according to any one of claims 55 to 61, wherein gravity brings the reactants into contact with the catalyst.

69. The method according to any one of claims 61 to 64, 67 and 68, wherein the reactants have a uniform flow over the catalyst.

70. The method according to any one of claims 61 to 64 and 67 to 69 wherein the reactants pass across the catalyst with a substantially even flow rate.

71. The method according to claim 70, wherein a substantially even flow rate is an instantaneous flow rate which is within ±10% of the average flow rate.

72. The method according to claim 71, wherein the liquid hourly space velocity of the reactants are from about 100 h^{-1} to about 10,000 h^{-1}.

73. The method according to any one of the claims 55 to 72, wherein the catalyst is solid.

74. The method according to claim 73, wherein the catalyst is of the formula x%Pt-y%Pd/[z%CZY-t%Al_2O_3-La_2O_3 doped].

75. The method according to any one of claims 55 to 74, comprising the step of cooling the catalyst.

76. The method according to claim 75, wherein the catalyst is cooled by passing a catalyst cooling fluid around the catalyst.

77. The method according to claim 75 or claim 76, wherein the catalyst is cooled by passing a catalyst cooling fluid through the catalyst in a separate vessel

78. The method according to claim 76 or claim 77, wherein the catalyst cooling fluid comprises water.

79. The method according to any one of claims 55 to 78, comprising the step of cooling the product mixture.

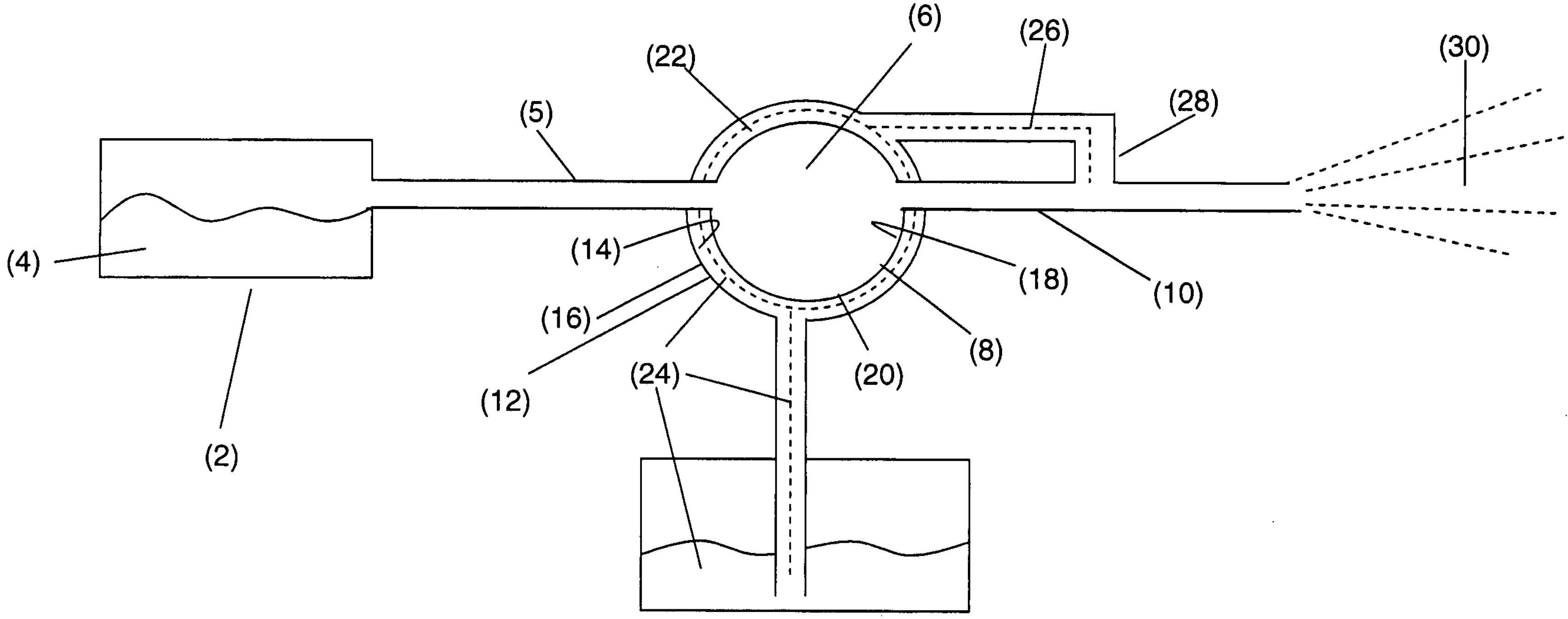
80. The method according to claim 79, wherein the product mixture is cooled by mixing the product mixture with an additive.

81. The method according to claim 80, wherein the additive is recycled catalyst cooling fluid.

82. The method according to claim 80 or claim 81, wherein the additive comprises steam.

83. The method according to any one of claims 80 to 82, wherein the additive comprises a cleaning fluid, such as a common detergent or degreasing agent, or a fragrance.

FIG. 1



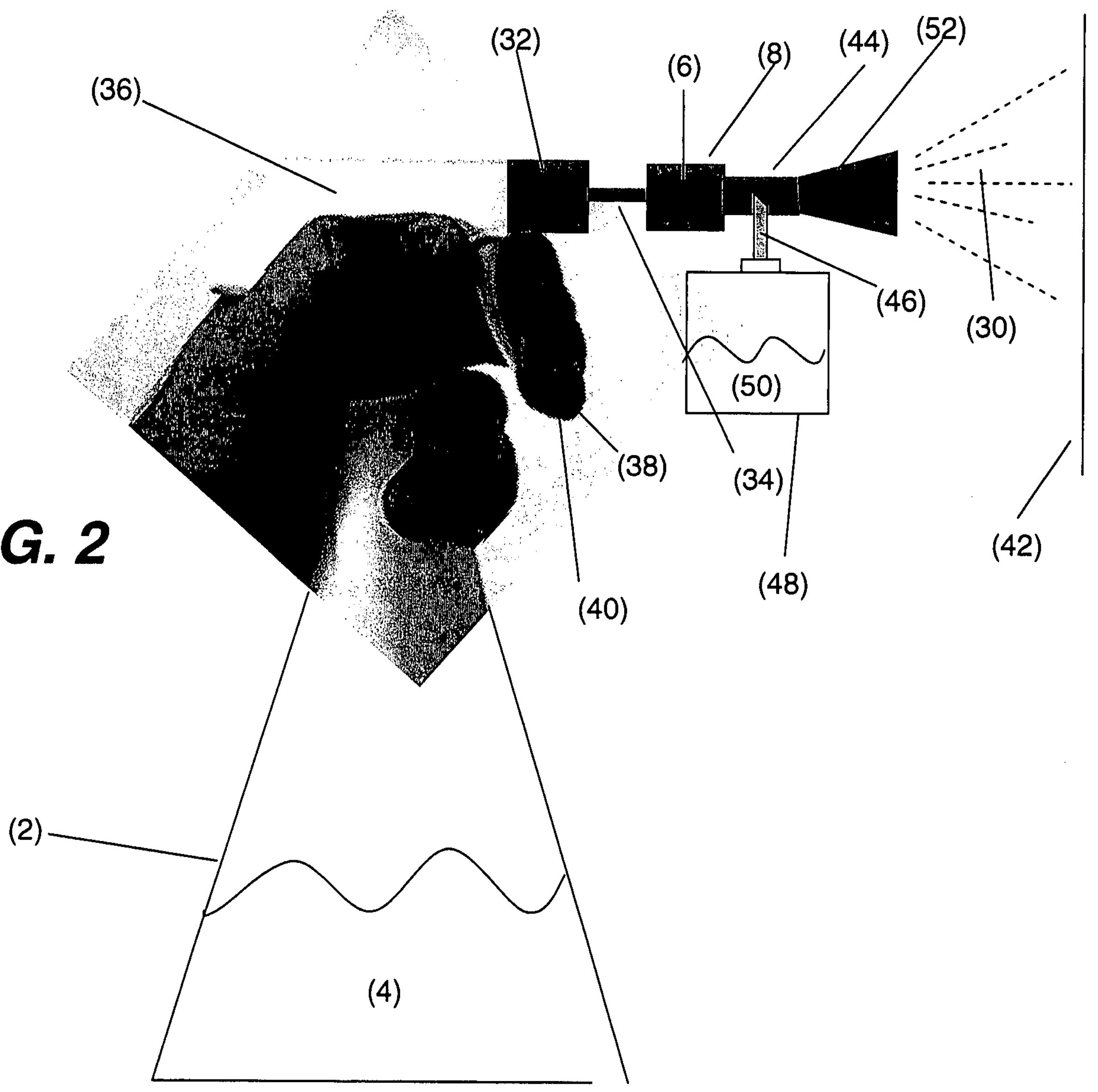


FIG. 2

FIG. 3

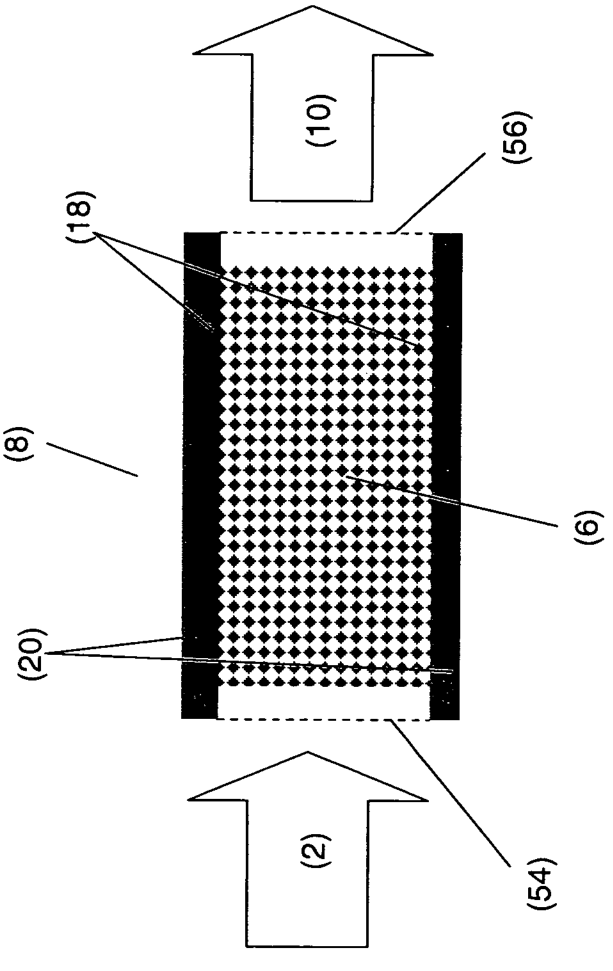
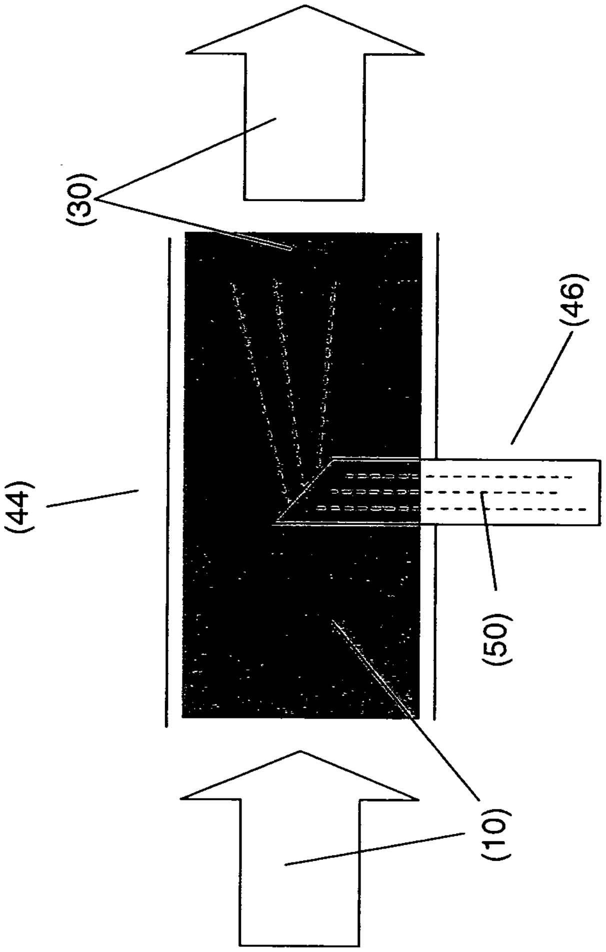


FIG. 4



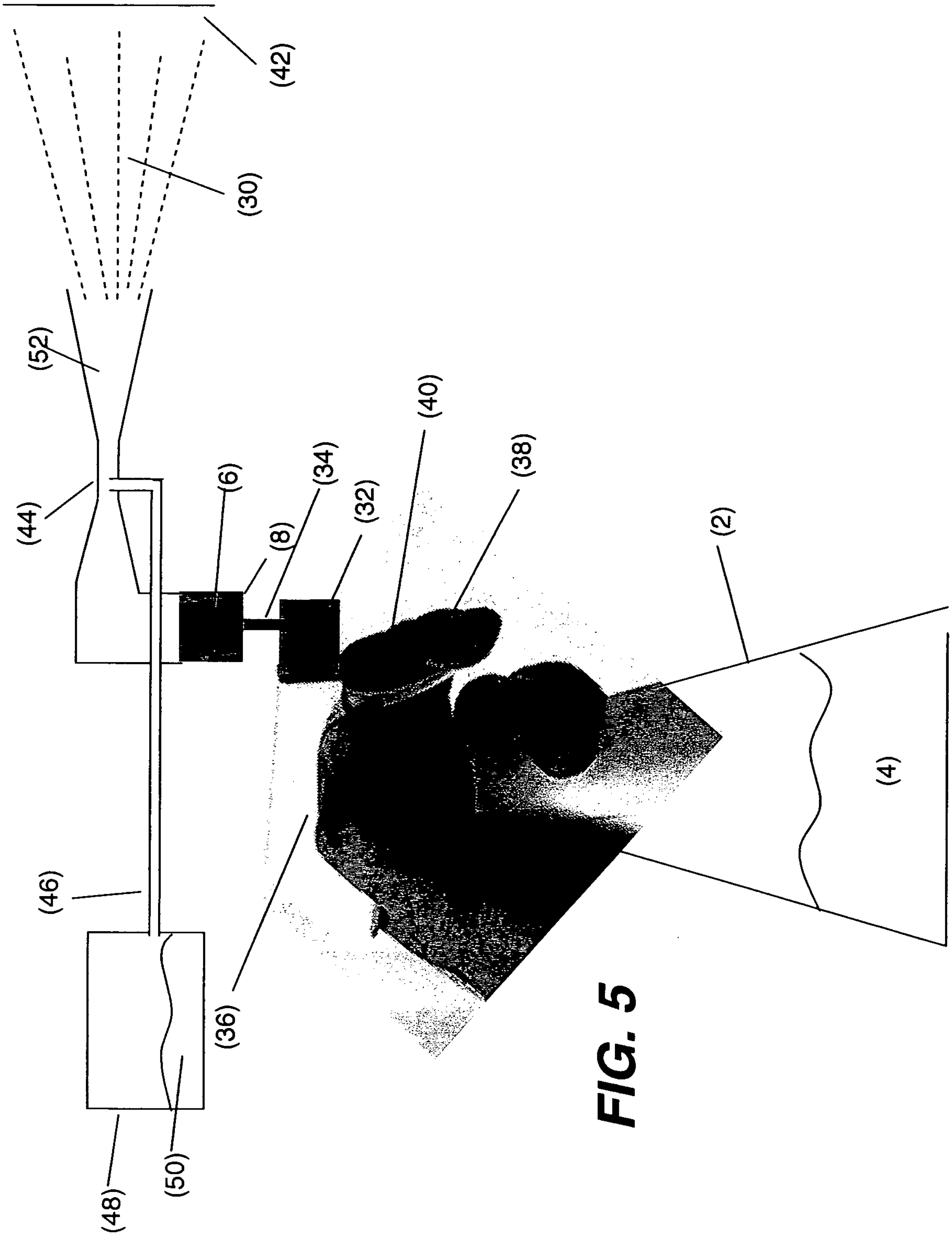


FIG. 5

FIG. 6

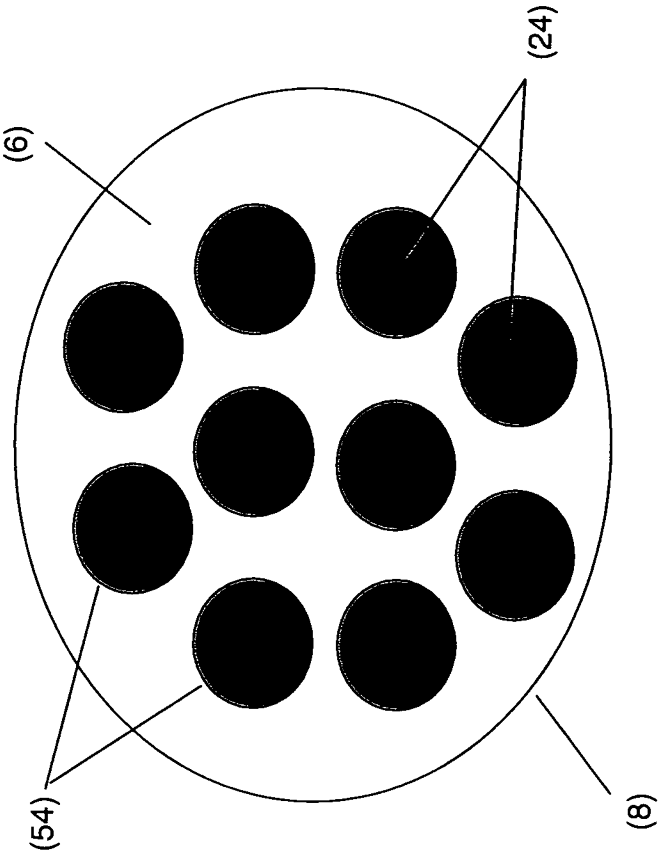


FIG. 7

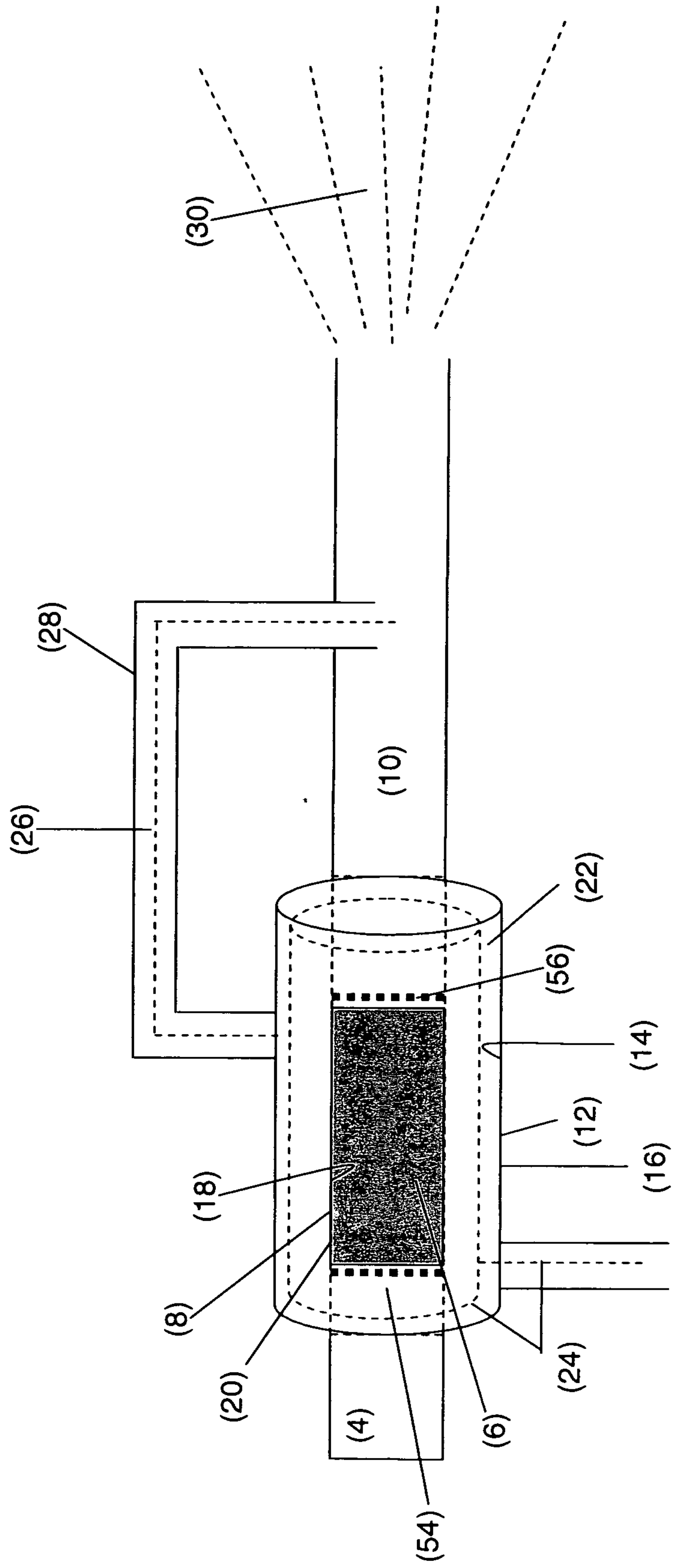


FIG. 8

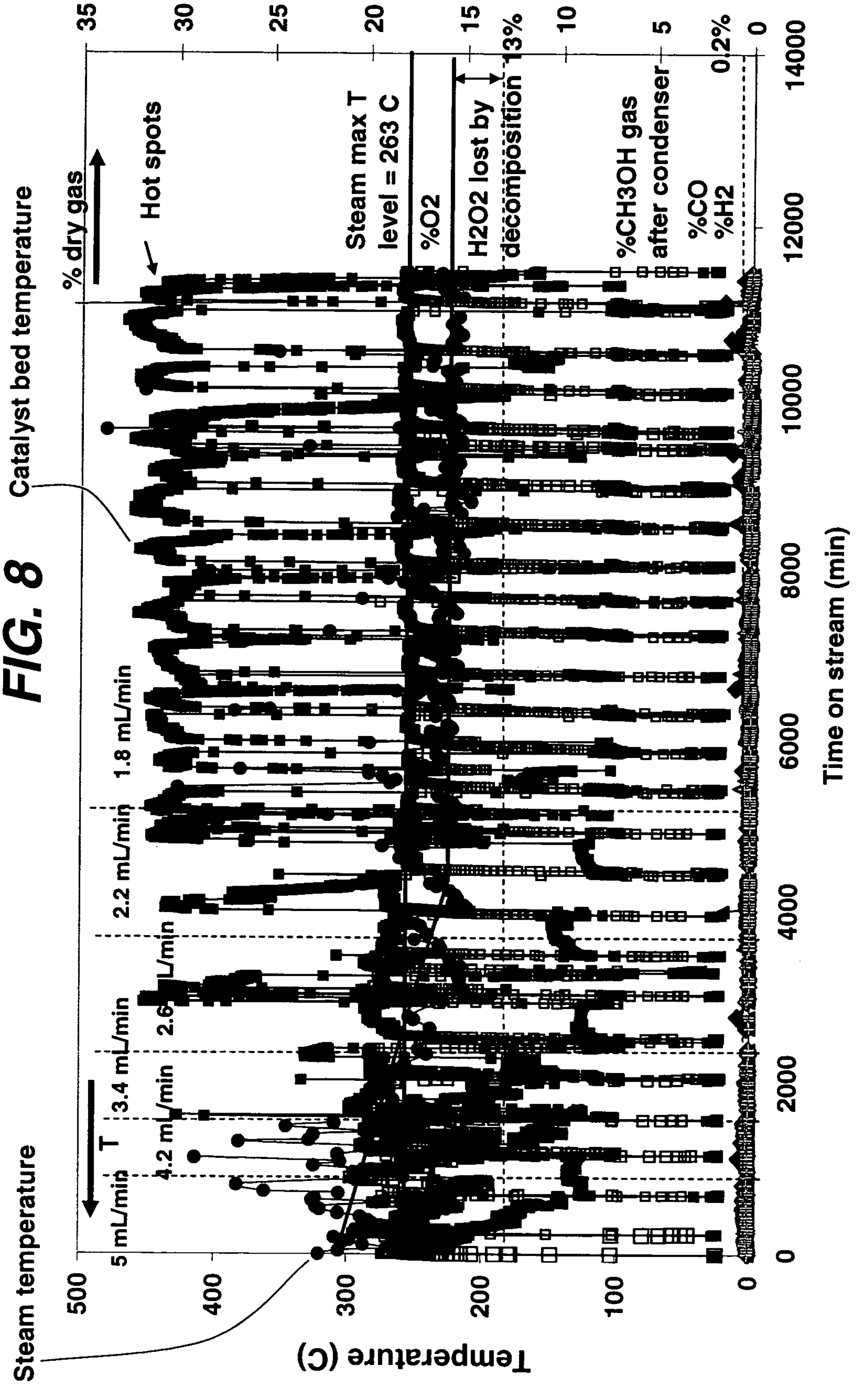

Steam temperature
Catalyst bed temperature
Temperature (C)
500
400
300
200
100
0
0
2000
4000
6000
8000
10000
12000
14000
Time on stream (min)
35
30
25
20
15
10
5
0
% dry gas
Hot spots
T
5 mL/min
4.2 mL/min
3.4 mL/min
2.6 mL/min
2.2 mL/min
1.8 mL/min
Steam max T level = 263 C
%O2
H2O2 lost by decomposition
13%
%CH3OH gas after condenser
%CO
%H2
0.2%

FIG. 9

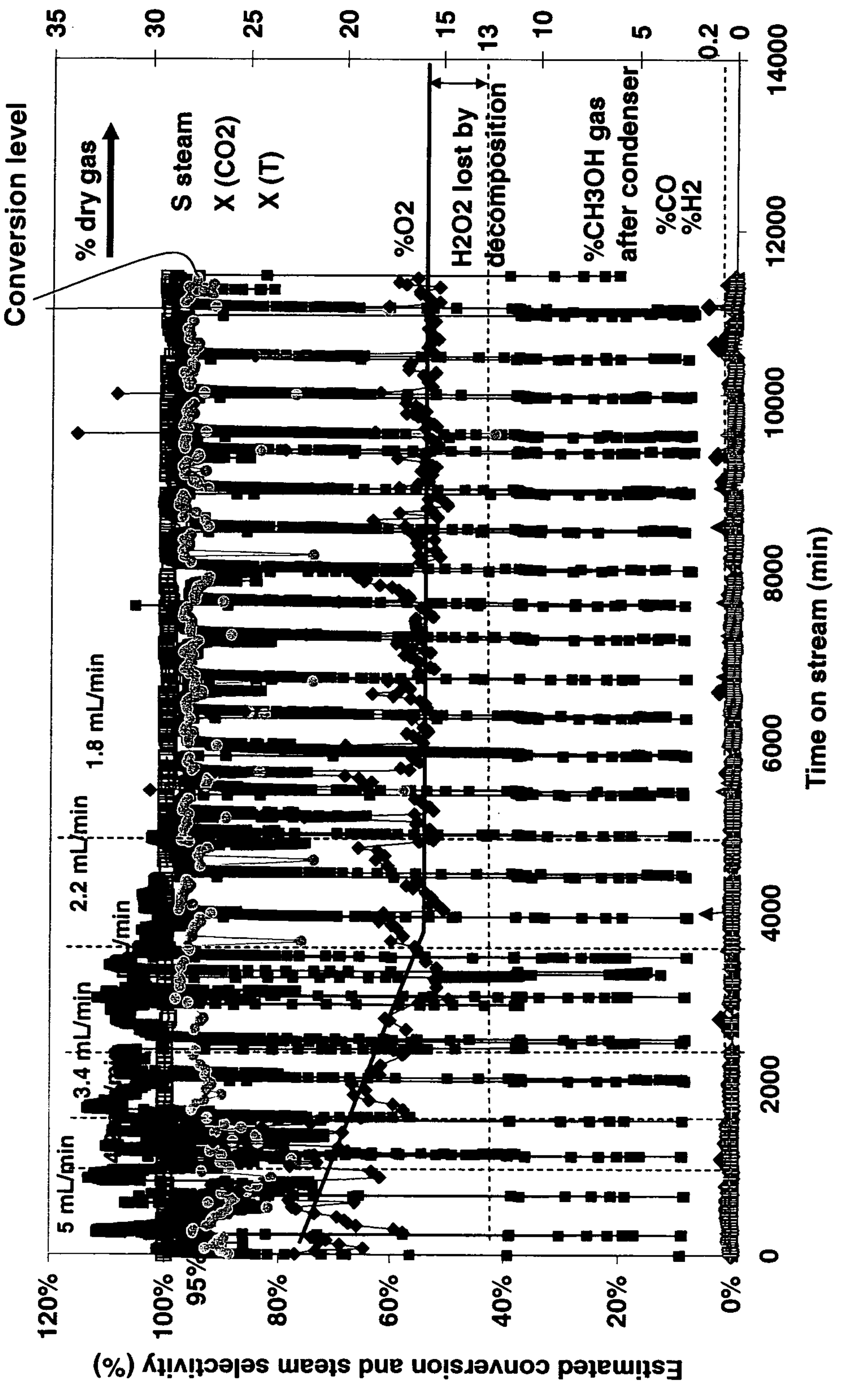
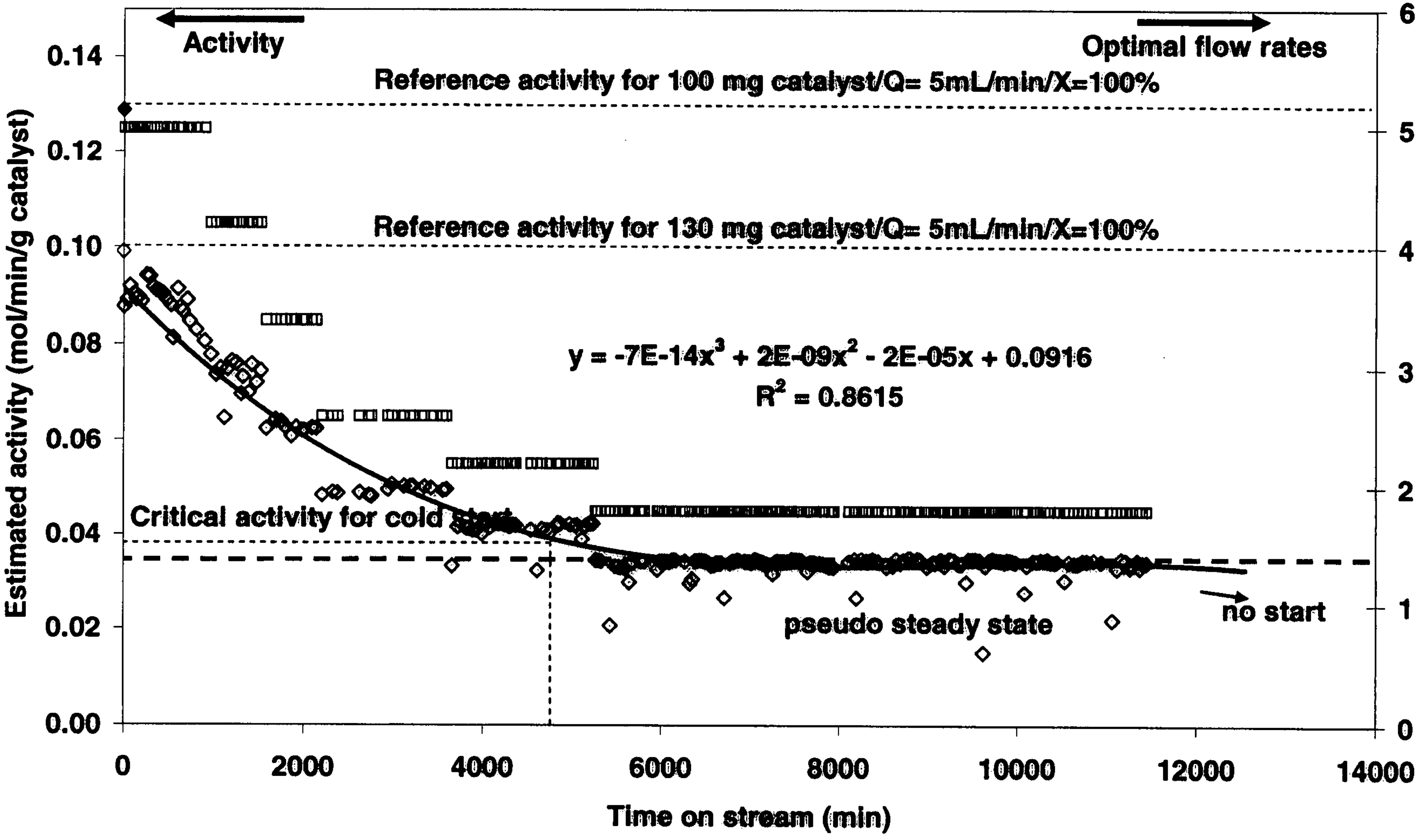

Conversion level
% dry gas
S steam
X (CO2)
X (T)
%O2
H2O2 lost by decomposition
%CH3OH gas after condenser
%CO
%H2
5 mL/min
3.4 mL/min
2.2 mL/min
1.8 mL/min
120%
100%
95%
80%
60%
40%
20%
0%
Estimated conversion and steam selectivity (%)
0
2000
4000
6000
8000
10000
12000
14000
Time on stream (min)
35
30
25
20
15
13
10
5
0.2
0

FIG. 10


Activity
Optimal flow rates
Reference activity for 100 mg catalyst/Q= 5mL/min/X=100%
Reference activity for 130 mg catalyst/Q= 5mL/min/X=100%
$y = -7E-14x^3 + 2E-09x^2 - 2E-05x + 0.0916$
$R^2 = 0.8615$
Critical activity for cold start
pseudo steady state
no start
Estimated activity (mol/min/g catalyst)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
2000
4000
6000
8000
10000
12000
14000
Time on stream (min)
6
5
4
3
2
1
0

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2008/002570

A. CLASSIFICATION OF SUBJECT MATTER
INV. B01J14/00 C01B13/02

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)
B01J C01B

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.
X	US 6 991 772 B1 (RUSEK JOHN J [US]) 31 January 2006 (2006-01-31) column 1, lines 25-31 column 5, lines 46-60; figure 3	1,53,54
X	US 4 185 073 A (MARSH DAVID R [US] ET AL) 22 January 1980 (1980-01-22) column 8, line 28 - column 10, line 4; figure 1	1,52-55
X	WO 03/011751 A (ATOFINA [FR]; REQUIEME BENOIT [FR]) 13 February 2003 (2003-02-13) page 5, lines 7-16 page 6, line 36 - page 7, line 15 page 8, lines 13-19; figure 1	1,52-55

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

☒ See patent family annex.

* Special categories of cited documents :

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 November 2008	04/12/2008

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, Fax: (+31-70) 340-3016	Buesing, Guenter

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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2008/002570

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2007/030846 A (SPIELBERGER PETER [AT]) 22 March 2007 (2007-03-22) page 7, paragraph 1-3; figure 1	1,52-55
X	US 4 342 876 A (KLINGMAN GILBERT E) 3 August 1982 (1982-08-03) column 2, lines 1-36 column 5, line 50 - column 6, line 6; figure 1	1,52-55
X	WO 2006/052296 A (CBH2 TECHNOLOGIES INC [US]; BARBER JEFFREY L [US]; CRONIN JEREMIAH J [) 18 May 2006 (2006-05-18) page 5, lines 17-21 page 10, lines 11-20; figure 2	1,52-54
X	US 3 665 803 A (FORSTEN IRVING ET AL) 30 May 1972 (1972-05-30) column 1, line 33 - column 2, line 5 column 2, line 43; figure 1	1,55

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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2008/002570

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			EP	1414742	A1	06-05-2004
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US 3665803	A	30-05-1972	NONE			