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PROCESS FOR THE CONTINUOUS PRODUCTION OF HYDROGEN PEROXIDE

The present invention relates to a process for the continuous production of hydrogen peroxide (H_2O_2).

10 More specifically, the present invention relates to a process for the continuous production of alcoholic or hydro-alcoholic solutions of hydrogen peroxide and their direct use in oxidation processes.

In particular, oxidation processes using hydrogen peroxide as oxidizing agent, are known in the art, in which
15 the use of alcoholic or hydro-alcoholic solutions object of the present invention have proved to be useful.

Examples of these processes are those using titanium silicalite as catalysts, such as the epoxidation of olefins
20 (EP-100,119), the ammoximation of carbonyl compounds (U.S. 4,794,198), the oxidation of ammonia to hydroxylamine (U.S. 5,320,819) and the hydroxylation of aromatic hydrocarbons (U.S. 4,369,783).

The industrial production of aqueous solutions of H_2O_2
25 by means of a complex two-step process, is known. In this

process a solution of an anthraquinone, such as butylan-
thraquinone or ethylanthraquinone, in an organic medium im-
miscible with water is first hydrogenated and then oxidized
with air to produce H_2O_2 which is subsequently extracted in
5 aqueous phase.

This process is expensive owing to the high investment
costs necessary for the complex production unit involved
and the necessity of separating and disposing of the by-
products generated during the oxidation phase and purifying
10 and reintegrating the anthraquinone solution before being
re-used.

For these reasons, processes for the direct synthesis
of hydrogen peroxide from H_2 and O_2 have been studied and
seem attractive from a technical and economic point of
15 view.

These processes generally use a catalytic system con-
sisting of a noble metal, particularly metals of the plati-
num group or their mixtures, in the form of salts or as
supported metals, reacting the two gases in a solvent con-
20 sisting of an aqueous medium or an aqueous-organic medium.

The embodiment of these processes however has proved
to be difficult on an industrial scale for the following
reasons:

A) the use of mixtures of H_2 and O_2 in concentrations
25 within the explosivity range, as the mixture becomes explo-

sive when the concentration of H_2 exceeds a value which, depending on the pressure and concentration of O_2 , varies from 4.5 to 6% by volume:

- B) even when operating outside the explosivity range of H_2-O_2 mixtures, the use of high concentrations of O_2 is risky to handle and not very compatible with the presence of flammable organic solvent mediums;
- C) the use in the reaction medium of high concentrations of promoters, for example acid, halogenated promoters and/or other additives, makes the catalytic system or H_2O_2 solution unstable. This makes it necessary to add stabilizers with costly purification operations of the H_2O_2 solution produced before its use;
- D) low productivity and selectivity of the reaction or the production of H_2O_2 solutions which are too dilute for economic industrial exploitation;
- E) low stability of the catalytic system under the reaction conditions.

For example, U.S. patents 3,361,533, 4,009,252 and 4,661,337 describe processes for the preparation of H_2O_2 which use gaseous mixtures of H_2 and O_2 which are typically included in the explosivity range.

To avoid these safety problems, some processes use ingenious and complex reactor solutions.

U.S. patent 5,194,242 describes a continuous process

for the preparation of H_2O_2 in aqueous solution which comprises the use of a suitable reactor and a mixture of H_2 and O_2 in ratios with each other within the explosivity range in the feeding to the reactor, but outside this range
5 in the gaseous stream leaving the reactor.

U.S. patent 5,641,467 describes a continuous process for the preparation of H_2O_2 from H_2 and O_2 which operates within the explosivity range of H_2/O_2 mixtures using a reaction apparatus suitable for producing a series of gas
10 bubbles sufficiently small and sufficiently dispersed and separate from each other in the liquid reaction medium as to avoid any possible explosion in the reactor.

These processes however are complex from an industrial point of view and their intrinsic safety is doubtful.

15 Numerous other processes describe, on the other hand, the use of mixtures of H_2 and O_2 poor in hydrogen, i.e. with concentrations of H_2 of less than 4-5% by volume with respect to the gaseous mixture, for the same purpose, i.e. to avoid safety problems deriving from the use of explosive
20 H_2-O_2 mixtures.

These processes, however, use extremely high concentrations of O_2 , whose use is only possible when operating in an aqueous solvent medium and they are therefore normally directed towards the production of aqueous H_2O_2 solutions,
25 tions, excluding the presence of organic mediums.

For example, U.S. patent 5,500,202 describes a continuous process for the preparation of aqueous solutions of H_2O_2 from H_2 and O_2 which operates in a "trickle bed" reactor using, in the feeding, a gaseous mixture of $H_2/O_2/N_2$ containing 4.6-6.2% by volume of H_2 and 57-62% by volume of O_2 , so that the mixture leaving the reactor is outside the explosivity range.

U.S. patent 4,279,883 describes a continuous process for the preparation of aqueous solutions of H_2O_2 from H_2 and O_2 characterized by a particular pre-treatment of the solution and catalyst with H_2 and in which the mixtures of gases at the outlet of the reactor is kept with the volume composition of 3% H_2 and 30% O_2 , the remaining percentage being N_2 .

International patent application WO 93/14025 describes a process for the preparation of aqueous solutions of H_2O_2 from H_2 and O_2 characterized by the use of particular catalysts and stabilizers of the catalytic activity and carried out in the presence of gaseous mixtures kept outside the explosivity limits of H_2 , with O_2 being fed in pure form or preferably mixed with N_2 to obtain a preferred $H_2/O_2/N_2$ composition equal to 3.2%/86.8%/10.0% respectively by volume.

International patent application WO 92/15520 describes a process for the preparation of aqueous solutions of H_2O_2 from H_2 and O_2 characterized by the use of particular cata-

lysts and stabilizers of the catalytic activity and carried out in the presence of gaseous mixtures kept outside the explosivity limits of H_2 , with O_2 being fed in pure form without inert gases.

5 European patent application EP-627,381 describes a process for the preparation of aqueous solutions of H_2O_2 from H_2 and O_2 characterized by the use of particular catalysts and carried out in the presence of gaseous mixtures kept outside the explosivity limits of H_2 in the presence
10 of inert gases such as nitrogen so as to obtain a preferred $H_2/O_2/N_2$ composition equal to 3%/47%/50% respectively by volume.

 In all these processes high concentrations of O_2 are used, which are scarcely compatible with the use of flammable organic reaction solvent mediums.
15

 In other cases, the use of mixtures of H_2 and O_2 outside the explosivity range and using low concentrations of O_2 prove to have a low reaction productivity and selectivity or to produce H_2O_2 solutions which are too dilute for
20 an economic industrial exploitation.

 For example U.S. patent 5,082,647 describes a process for the preparation of aqueous solutions of H_2O_2 from H_2 and O_2 characterized by the use of particular catalysts and carried out in a trickle bed reactor, feeding a gaseous
25 mixture containing 3% of H_2 by volume in air. In the exam-

ple described, after 5 hours the solution re-circulated through the reactor contained 0.3% of H_2O_2 .

From what is specified above, the objective of setting up a process for the direct synthesis of H_2O_2 from H_2 and O_2 which can be used on an industrial scale under safety and economically advantageous conditions, does not appear to have been reached as yet.

In particular, the objective of producing stable solutions of H_2O_2 in aqueous-organic mediums with a concentration suitable for direct use in oxidation processes, on an industrial scale and under safety and economically advantageous conditions, seems even more difficult to reach.

For example, U.S. patents 4,389,390 and 4,336,238 describe a continuous process for the preparation of aqueous-organic solutions of H_2O_2 from H_2 and O_2 which use a vertical tubular catalytic packed reactor operating in equicurrent of gas and liquid and using a gaseous mixture of H_2/O_2 in the feeding, containing 6.3% by volume of H_2 and 95.7% by volume of O_2 .

European patent applications EP-787,681 and EP-812,836, directed towards the production of aqueous-alcoholic solutions of H_2O_2 and their use in the epoxidation of propylene, describe processes for the preparation of these solutions in the presence of a halide and a metal of the platinum group, with the use of $H_2/O_2/N_2$ mixtures

having a composition equal to 2.4%/24%/73.6% respectively by volume, or using H_2 diluted in air outside the explosivity limits, in which the concentration of H_2O_2 in the solutions obtained ranges from 0.05% to 0.39% by weight.

5 International patent application WO 98/16463 likewise describes a process directed towards the production of aqueous-alcoholic solutions containing at least 2.5% by weight of H_2O_2 , carried out on monolithic formed catalytic bodies, which uses mixtures of H_2 and O_2 , optionally in
10 the presence of inert gases, or mixtures of H_2 and air outside the explosivity limits for H_2 .

The illustrative examples of this document however all comprise the use of mixtures of H_2 with pure O_2 . In addition, from the examples it can be observed that when the
15 gas stream fed to the reactor is within the explosivity limits (H_2 concentration equal to 10% by volume in pure O_2), solutions of H_2O_2 are obtained at 4-7% by weight with selectivities with respect to H_2 ranging from 70 to 82%. Viceversa, when a gas stream is used in the feeding outside
20 the explosivity limits, (concentration of H_2 equal to 4% by volume in pure O_2), the concentration of H_2O_2 obtained does not exceed 2.7% and the selectivity calculated with respect to H_2 drops to 68%.

Therefore not even this process overcomes the problems
25 deriving from the use of explosive mixtures of H_2-O_2 and

from the poor compatibility of high concentrations of O₂ with flammable organic reaction mediums.

It has now been found, according to the present invention, that it is possible to overcome the drawbacks of the known art discussed above, using a bimetal catalyst based on palladium and platinum as active components, a liquid reaction medium consisting of an alcohol or an alcohol-water mixture with a prevalent alcoholic content and a gaseous stream containing hydrogen, oxygen and an inert gas, in which the concentration of hydrogen is less than 4.5% by volume, the concentration of oxygen is less than 21% by volume, the complement to 100 being inert gas, to produce alcoholic or alcohol-aqueous solutions of H₂O₂ at a concentration ranging from 2 to 10% by weight with a high reaction productivity and selectivity and a high stability of the catalytic activity over a period of time.

These reaction conditions provide substantial advantages, in particular:

(1) The possibility of carrying out the process under high safety conditions, with respect to the handling of both hydrogen-oxygen mixtures and alcohol-oxygen mixtures. In fact, operating below 4.5% by volume of hydrogen is well outside the explosivity zone of H₂-O₂-inert gas mixtures. Similarly, when operating below 21% by volume of O₂, risks deriving from the presence of alcohol in the gaseous phase,

owing to the reduced quantity of fuel in the reaction medium, are minimized.

In addition, the concentration of H_2O_2 in the solutions produced according to the invention is such that
5 there are no instability phenomena linked to the presence of organic solvent, phenomena which normally occur at much higher concentrations.

(2) The possibility of minimizing the concentrations of acid and halogenated promoter present in the liquid reaction medium. This has beneficial effects on the stability
10 of the catalytic system, on the stability of the H_2O_2 solutions obtained and on the possibility of the direct use of the above solutions in the oxidation processes mentioned above.

(3) The production of solutions of hydrogen peroxide with
15 a composition and concentration adequate for direct use and economically valid in oxidation processes, generally ranging from 2% to 10% by weight.

In accordance with this, the present invention relates
20 to a process for the continuous production of alcoholic or hydro-alcoholic solutions with a prevalent alcoholic content of hydrogen peroxide, which comprises:

(a) feeding to a reactor, which contains a catalyst based on palladium and platinum, heterogeneous and maintained in
25 dispersion in a liquid reaction medium:

- (i) a liquid stream consisting of an alcohol or an alcohol-water mixture with a prevalent alcoholic content containing an acid promoter and a halogenated promoter;
- (ii) a gaseous stream containing hydrogen, oxygen and an inert gas, characterized in that the concentration of hydrogen is lower than 4.5% by volume and the concentration of oxygen is lower than 21% by volume, the complement to 100 being an inert gas;
- (b) removing from the reactor:
- 10 (iii) a liquid stream essentially consisting of the stream (i) and also containing hydrogen peroxide and the water produced by the reaction, characterized in that the concentration of hydrogen peroxide ranges from 2% to 10% by weight; and
- 15 (iv) a gaseous stream essentially consisting of non-reacted hydrogen and oxygen and the inert gas.

The reactor used can be any reactor suitable for operating in continuous and conducting the reaction in a triphasic system such as that described, obtaining an effective contact between the gaseous phase, liquid phase and the catalyst maintained in dispersion (so-called slurry system).

Reactors suitable for the purpose are, for example, stirred reactors, bubble reactors, gas-lift reactors with internal or external circulation, as described in the art.

The reactor is kept under suitable temperature and pressure conditions. According to the process object of the present invention, the temperature normally ranges from -10°C to 60°C, preferably from 0°C to 40°C. The pressure
5 normally ranges from 1 to 300 bars, preferably from 40 to 150 bars.

The residence time of the liquid medium in the reactor normally ranges from 0.05 to 5 hours, preferably from 0.10 to 2 hours.

10 The catalyst which can be used for the purposes of the present invention is a heterogeneous catalyst containing palladium and platinum as active components.

In these catalysts, the palladium is normally present in a quantity ranging from 0.1 to 3% by weight and the
15 platinum in a quantity ranging from 0.01 to 1% by weight, with an atomic ratio between platinum and palladium ranging from 1/500 to 100/100.

The palladium is preferably present in a quantity ranging from 0.4 to 2% by weight and the platinum in a
20 quantity ranging from 0.02 to 0.5% by weight, with an atomic ratio between platinum and palladium ranging from 1/200 to 20/100.

In addition to palladium and platinum, other metals of group VIII or IB, such as for example, ruthenium, rhodium,
25 iridium and gold, can be present as active components or

promoters, in a concentration generally not higher than that of the palladium.

The catalyst can be prepared by dispersing the active components on an inert carrier by means of precipitation and/or impregnation starting from precursors consisting for example of solutions of their salts or soluble complexes, and then reduced to the metal state by means of thermal and/or chemical treatment with reducing substances such as hydrogen, sodium formate, sodium citrate using preparative techniques well known in the art.

The inert carrier may typically consist of silica, alumina, silica-alumina, zeolites, activated carbon, and other materials well known in the art. Activated carbon is preferred for the preparation of the catalysts useful for the invention.

Activated carbons which can be used for the purposes of the invention are selected from those of a fossil or natural origin deriving from wood, lignite, peat or coconut and having a surface area greater than 300 m²/g and which can reach 1400 m²/g, in particular those having a surface area greater than 600 m²/g.

Preferred activated carbons are those with a low ash content.

Sulfonated activated carbons described in Italian patent application MI 98A01843 are also useful for the pur-

pose.

Before supporting or impregnating the metals, the activated carbon can be subjected to treatment such as washing with distilled water or treatment with acids, bases or
5 diluted oxidizing agents, for example acetic acid, hydrochloric acid, sodium carbonate and hydrogen peroxide.

The catalyst is normally dispersed in the reaction medium at a concentration ranging from 0.1 to 10% by weight, preferably from 0.3 to 3% by weight.

10 The liquid stream (i) consists of an alcohol or mixture of C₁-C₃ alcohols or a mixture of these alcohols with water with a prevalent alcoholic content. A mixture with a prevalent alcoholic content means a mixture containing more than 50% by weight of alcohol or mixture of alcohols. Among
15 C₁-C₃ alcohols methanol is preferred for the purposes of the present invention. Among the mixtures, a mixture of methanol and water containing at least 70% by weight of methanol, is preferred.

The liquid stream also contains an acid promoter and
20 halogenated promoter.

The acid promoter can be any substance capable of generating H⁺ hydrogen ions in the liquid reaction medium and is generally selected from inorganic acids such as sulfuric, phosphoric, nitric acids or from organic acids such as
25 sulfonic acids. Sulfuric acid and phosphoric acid are pre-

ferred. The concentration of the acid generally ranges from 20 to 1000 mg per kg of solution and preferably from 50 to 500 mg per kg of solution.

The halogenated promoter can be any substance capable
5 of generating halogen ions in the liquid reaction medium. Substances capable of generating bromide ions are preferred. These substances are generally selected from hydrobromic acid and its salts soluble in the reaction medium, for example alkaline bromides, hydrobromic acid being pre-
10 ferred. The concentration of halogenated promoter generally ranges from 0.1 to 50 mg per kg of liquid medium and preferably from 1 to 10 mg per kg of liquid medium.

The gaseous stream (ii) at the inlet contains a concentration of hydrogen of less than 4.5% by volume and a
15 concentration of oxygen of less than 21% by volume, the complement to 100 being an inert gas, which is generally selected from nitrogen, helium, argon. Said gas is preferably nitrogen.

In the gaseous stream (ii) the concentration of hydro-
20 gen preferably ranges from 2% to 4% by volume and the concentration of oxygen preferably ranges from 6% to 15% by volume.

The oxygen can be supplied in said stream using as raw material, pure or substantially pure oxygen, enriched air,
25 containing for example from 21 to 90% of oxygen or air, the

composition of the stream then being brought to the desired values, defined above, by the addition of a suitable concentration of inert gas.

The liquid stream (iii) at the outlet of the reactor
5 normally has a concentration of hydrogen peroxide ranging from 2% to 10% by weight and preferably from 3% to 8% by weight. It also contains the acid promoter and halogenated promoter in quantities equal to those introduced together with the liquid stream fed, and water in a quantity equal
10 to that introduced with the liquid stream fed, to which the water obtained as reaction by-product is added. The latter normally represents an additional concentration ranging from 0.5% to 2.5% by weight.

The liquid stream (iii) is separated from the catalyst
15 by means of filtration techniques well known in the art, for example by the use of filter plugs situated inside the reactor or in a specific re-circulation cycle of the reaction mixture, outside the reactor. In this latter case the tangential filtration technique can also be conveniently
20 used.

The liquid stream (iii) is stable to storage without the necessity of adding stabilizing substances and is suitable for direct use in oxidation processes downstream such as the ammoximation of cyclohexanone to cyclohexanone-oxime
25 in the presence of ammonia and H_2O_2 and the oxidation reac-

tion with H_2O_2 of propylene to propylene oxide.

The gaseous stream (iv) at the outlet of the reactor, essentially consisting of non-reacted hydrogen and oxygen and of the inert gas, generally contains a volume concentration of hydrogen equal to or lower than 2%, normally ranging from 0.5 to 1.5%, and a volume concentration of oxygen generally lower than 18%, normally ranging from 6% to 12%.

In an embodiment of the process of the present invention, the gaseous stream at the outlet of the reactor is recycled to the feeding to the reactor, after flushing from the system, the fraction necessary for eliminating the quantity of inert gas introduced in excess with the feeding particularly when air is used as oxygen source. In this case, the gaseous stream (ii) fed to the reactor consists of the recycled fraction of the above stream (iv), with the addition of a quantity of hydrogen and oxygen (as such or in the form of air or enriched air) essentially equal to that used up by the reaction and that flushed.

According to another embodiment of the process of the present invention, the gaseous stream (iv) leaving the reactor is fed to one or more subsequent reactors operating analogously to the one previously described, after adding each time a quantity of hydrogen and oxygen (as such or in the form of air or enriched air) essentially equal to that

used up by the reaction which takes place in the single reactors.

Operating under the above conditions, it is possible to produce hydrogen peroxide under safety conditions with a reaction productivity normally ranging from 30 to 200 g of H_2O_2 (expressed as 100% H_2O_2) per liter of reaction medium per hour and with a molar selectivity towards the formation of H_2O_2 , referring to the hydrogen used up, generally higher than 65%.

The following examples are illustrative but do not limit the scope of the invention described.

EXAMPLE 1

Treatment of the carrier

50 g of activated maritime pine charcoal in powder form (CECA) and 500 ml of distilled water are charged into a 1 liter glass flask. After 2 hours at 80°C, the charcoal is filtered and washed with 500 ml of distilled water.

The carbon, still damp, is then charged into the 1 liter flask and after adding 500 ml of a solution at 2% by weight of HCl, the temperature is brought to 80°C. After about 2 hours, the mixture is cooled and the activated carbon is washed on a filter with distilled H_2O until the chlorides have been eliminated. The washed activated carbon is recovered and dried in an oven at 120°C for 2 hours.

25 EXAMPLE 2

Preparation of the catalyst 1%Pd-0.1%Pt/C

10 g of activated carbon treated as described in example 1, are charged into a 0.5 liter glass flask, containing 100 ml of distilled water and 0.32 g of Na_2CO_3 . The suspension is maintained at room temperature (20-25°C), under stirring, for 10 minutes.

10 ml of an aqueous solution containing 1.0 g of a solution of Na_2PdCl_4 at 10% by weight of Pd and 0.1 g of a solution of H_2PtCl_6 at 10% by weight, are subsequently added dropwise over a period of about 10 minutes.

The suspension is kept at room temperature for 10 minutes and is then heated in a water bath for 10 minutes to 90°C. A solution containing 0.85 g of sodium formate in 10 ml of water is then added and the stirring is continued at 90°C for 2 hours.

After cooling to room temperature, the suspension is filtered and the catalyst recovered is washed with distilled water until the chlorides have been eliminated and dried in an oven at 120°C for 2 hours.

20 EXAMPLE 3

Preparation of the catalyst 1% Pd/C

The same procedure is used as in example 2, but using 10 ml of an aqueous solution containing 1.0 g of a solution of Na_2PdCl_4 at 10% by weight of Pd.

25 EXAMPLE 4

Preparation of the catalyst 1% Pt/C

The same procedure is used as in example 2, but using 10 ml of an aqueous solution containing 1.0 g of a solution of H_2PtCl_6 at 10% by weight.

5 EXAMPLE 5

Synthesis of H_2O_2

A micropilot plant is used, consisting of a Hastelloy C autoclave having a volume of 400 ml, equipped with a thermostat-regulation system, a magnetic drag stirring system, a regulation and control system of the pressure during the reaction, a filter for continuously removing the liquid phase containing the reaction products, a feeding system of the mixture of the solvent and promoters in which the reaction takes place, a feeding system of the gaseous reagents and a series of regulation and control instruments.

The reaction trend is followed by continuously analyzing the hydrogen and oxygen in the feeding and at the outlet of the reactor.

The concentration of H_2O_2 which is formed is determined in the reactor liquid effluent by titration with potassium permanganate. The selectivity with respect to the converted hydrogen is calculated on the basis of the concentration of H_2O_2 in the reaction effluent and on the basis of analysis of the H_2 leaving the reactor, once the stationary state has been reached in the reactor.

1.2 g of catalyst prepared as described in example 2 and 150 g of methanol:water solution (95/5 by weight) containing 6 ppm of HBr and 300 ppm of H₂SO₄ are charged into the reactor.

5 The autoclave is pressurized, without stirring, at 100 bars with a gaseous mixture consisting of 3.6% of H₂, 11% of O₂ and 85.4% of N₂ by volume. The stirring is then started up to 800 revs/minute, the pressure is maintained with a continuous stream, 810 normal liters (Nl), of the
10 same gaseous mixture, and 300 g/hour of a methanol:water solution having the composition defined above, is fed at the same time. The temperature inside the reactor is kept at 8°C. The results are indicated in Table 1.

Table 1

15

Hrs of reaction	H ₂ O ₂ wt %	Molar selectivity H ₂ O ₂ %
10	6.8	67
100	6.9	70
200	7.0	71
300	6.9	69
400	7.1	71
500	7.2	73
600	7.1	72
700	7.3	74
800	7.2	73

25

EXAMPLE 6 (comparative)

Synthesis of hydrogen peroxide in the presence of the catalyst Pd/C

Example 5 is repeated using the catalyst prepared in example 3.

The results obtained are indicated in Table 2.

Table 2

Hrs of reaction	H ₂ O ₂ wt %	Molar selectivity
		H ₂ O ₂ %
5	0.7	30
10	0.6	32

EXAMPLE 7 (comparative)

Synthesis of hydrogen peroxide in the presence of the catalyst Pt/C

Example 5 is repeated using the catalyst prepared in example 4.

The results obtained are indicated in Table 3.

Table 3

Hrs of reaction	H ₂ O ₂ wt %	Molar selectivity
		H ₂ O ₂ %
5	1.5	20
10	1.3	24

EXAMPLE 8 (comparative)

The reaction is carried out as described in example 5,

but using 150 g of water instead of the hydro-alcoholic mixture. The results obtained are indicated in Table 4.

Table 4

Hrs of reaction	H ₂ O ₂ wt %	Molar selectivity H ₂ O ₂ %
5	2	64
10	1.8	62
20	1.7	60
30	1.8	61



CLAIMS

1. A process for the continuous production of alcoholic or hydro-alcoholic solutions with a prevalent alcoholic content, of hydrogen peroxide, which comprises:
- 5 (a) feeding to a reactor, which contains a catalyst based on palladium and platinum, heterogeneous and maintained in dispersion in a liquid reaction medium:
- 10 (i) - a liquid stream consisting of an alcohol or an alcohol-water mixture with a prevalent alcoholic content containing an acid promoter and a halogenated promoter;
- 15 (ii) a gaseous stream containing hydrogen, oxygen and an inert gas, characterized in that the concentration of hydrogen is lower than 4.5% by volume and the concentration of oxygen is lower than 21% by volume, the complement to 100 being an inert gas;
- 20 (b) removing from the reactor:
- (iii) a liquid stream consisting of the stream (i) and also containing hydrogen peroxide and the water produced by the reaction, characterized in that the concentration of hydrogen peroxide ranges from 2% to 10% by weight; and
- 25 (iv) a gaseous stream essentially consisting of non-reacted hydrogen and oxygen and the inert gas.



2. The process according to claim 1, wherein the catalyst contains palladium in a quantity ranging from 0.1 to 3% by weight and platinum in a quantity ranging from 0.01 to 1% by weight, with an atomic ratio between platinum and palladium ranging from 1/500 to 100/100.
3. The process according to claim 2, wherein the catalyst contains a quantity of palladium ranging from 0.4 to 2% by weight and a quantity of platinum ranging from 0.02 to 0.5% by weight, with an atomic ratio between platinum and palladium ranging from 1/200 to 20/100.
4. The process according to claim 1, 2 or 3, wherein the catalyst in addition to palladium and platinum, contains another metal selected from those of group VIII or IB.
5. The process according to claim 4, wherein the metal is ruthenium, rhodium, iridium or gold.
6. The process according to any one of the preceding claims, wherein the catalyst is prepared by dispersing the active components on an inert carrier by means of precipitation and/or impregnation.
7. The process according to claim 6, wherein the inert carrier is selected from silica, alumina, silica-alumina, zeolites, activated carbon and activated carbon functionalized with sulfonic groups.
8. The process according to claim 7, wherein the carrier is an activated carbon selected from those of a fossil



or natural origin deriving from wood, lignite, peat or coconut and having a surface area greater than 300 m²/g.

9. The process according to claim 7 or 8, wherein the carrier
5 is an activated carbon having a surface area which can reach a value of 1400 m²/g.
10. The process according to claim 7 or 8, wherein the carrier is an activated carbon having a surface area greater than 600 m²/g.
- 10 11. The process according to claim 7, 8 or 9, wherein the activated carbon has a low ash content.
12. The process according to any one of the preceding claims, wherein the catalyst is dispersed in the reaction medium at a concentration ranging from 0.1 to 10% by weight.
- 15 13. The process according to claim 12, wherein the catalyst is dispersed in the reaction medium at a concentration ranging from 0.3 to 3% by weight.
14. The process according to any one of the preceding claims, wherein the liquid
20 stream (i) consists of an alcohol or a mixture of C₁-C₃ alcohols or a mixture of said alcohols with water with an alcoholic content higher than 50%.
15. The process according to claim 14, wherein the alcohol is methanol.
- 25 16. The process according to claim 14, wherein the mixture is a mixture of methanol and water containing at least



70% by weight of methanol.

17. The process according to any one of the preceding claims, wherein the halogenated promoter is a substance capable of generating halogen ions in the reaction medium.
- 5 18. The process according to claim 17, wherein the halogenated promoter is selected from substances capable of generating bromide ions such as hydrobromic acid and its salts soluble in the reaction medium, such as alkaline bromides.
- 10 19. The process according to claim 18, wherein the promoter is hydrobromic acid.
20. The process according to any one of the preceding claims, wherein the concentration of halogenated promoter ranges from 0.1 to 50 mg per kg of solution.
- 15 21. The process according to claim 18, wherein the concentration of halogenated promoter ranges from 1 to 10 mg per kg of solution.
22. The process according to any one of the preceding claims, wherein the acid promoter is selected from substances capable of generating H^+ hydrogen ions in the reaction medium.
- 20 23. The process according to claim 22, wherein the acid promoter is selected from inorganic acids such as sulfuric, phosphoric, nitric acid or from organic acids such as sulfonic acids.
- 25 24. The process according to claim 23, wherein the acid



promoter is sulfuric acid or phosphoric acid.

25. The process according to any one of the preceding claims, wherein the concentration of acid promoter ranges from 20 to 1000 mg per kg of solution.
- 5 26. The process according to claim 25, wherein the concentration of acid promoter ranges from 50 to 500 mg per kg of solution.
27. The process according to any one of the preceding claims, wherein in the gaseous stream (ii), the concentration of hydrogen ranges from 2% to 4.5% by volume and the concentration of oxygen ranges from 6% to 15% by volume, the complement to 100 being an inert gas selected from nitrogen, helium and argon.
- 10 28. The process according to claim 27, wherein the inert gas is nitrogen.
- 15 29. The process according to any one of the preceding claims, wherein in the gaseous stream (ii) the oxygen can be supplied using as raw material, pure or substantially pure oxygen, enriched air, containing from 21 to 90% of oxygen or air, the composition of the stream then being brought to the desired value by the addition of a suitable concentration of inert gas.
- 20 30. The process according to claim 29, wherein the liquid stream (iii) leaving the reactor has a concentration of hydrogen peroxide ranging from 3% to 8% by weight.
- 25



31. The process according to any one of the preceding claims, wherein the liquid stream (iii) is separated from the catalyst by means of filtration techniques.
- 5 32. The process according to claim 31, wherein the filtration is carried out using filter plugs situated inside the reactor or by means of tangential filtration.
- 10 33. The process according to any one of the preceding claims, wherein the gaseous stream (iv) leaving the reactor, essentially consisting of non-reacted hydrogen and oxygen and inert gas, contains a volume concentration of hydrogen equal to or lower than 2% and a volume concentration of oxygen lower than 18%.
- 15 34. The process according to claim 33, wherein the gaseous stream (iv) leaving the reactor contains a volume concentration of hydrogen ranging from 0.5 to 1.5% and a volume concentration of oxygen ranging from 6 to 12%.
- 20 35. The process according to any one of the preceding claims, wherein the gaseous stream (iv) leaving the reactor is recycled to the feeding to the reactor, after flushing from the system the fraction necessary for eliminating the quantity of inert gas introduced in excess with the feeding and addition of H_2 and O_2 used up in the process.
- 25 36. The process according to any one of the preceding claims, wherein the gaseous stream (iv) leaving the reactor is fed to one or more subsequent reactors operating analogously to that de-



scribed in claim 1, after the addition each time of a quantity of hydrogen and oxygen essentially equal to that used up by the reaction which takes place in the single reactors.

- 5 37. The process according to any one of the preceding claims, wherein the reaction is carried out at a temperature ranging from -10 to 60°C.
38. The process according to claim 37, wherein the temperature ranges from 0 to 40°C.
- 10 39. The process according to any one of the preceding claims, wherein the reaction is carried out at a total pressure ranging from 1 to 300 bars.
40. The process according to claim 39, wherein the total pressure ranges from 40 to 150 bars.
- 15 41. The process according to any one of the preceding claims, wherein the reactor is a reactor suitable for operating in continuous and carrying out the reaction in a triphasic system, obtaining an effective contact between the gas phase, the liquid phase and the catalyst held in dispersion.
- 20 42. The process according to claim 41, wherein the reactor is selected from stirred reactors, bubble reactors or gas-lift reactors with internal or external circulation.
- 25 43. The process according to any one of the preceding claims, wherein the residence time of the liquid medium in the reactor ranges



from 0.05 to 5 hours.

44. The process according to claim 43, wherein the residence time of the liquid medium in the reactor ranges from 0.1 to 2 hours.

5 45. The process according to any one of the preceding claims, wherein the liquid stream (iii) is used directly in an oxidation process of a substrate selected from olefins, aromatic hydrocarbons, ammonia and carbonyl compounds using titanium silicalite as catalysts.

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