

NEW CATALYST, PROCESS FOR THE PRODUCTION OF HYDROGEN  
PEROXIDE AND ITS USE IN OXIDATION PROCESSES

The present invention relates to a catalyst  
consisting of a metal of the VIII group supported on  
5 acid activated carbon functionalized with sulfonic  
groups, a process for the direct synthesis of hydrogen  
peroxide from hydrogen and oxygen which uses said  
catalyst and the use of the hydrogen peroxide solution  
in oxidation processes catalyzed by titanium-silicali-  
10 te.

Hydrogen peroxide is a commercially important  
product which is widely used as bleaching agent in the  
textile and paper industries, in the environmental  
field as a biocide and in the chemical industry.

15 In particular the use of hydrogen peroxide is  
known in the art in a series of oxidation reactions  
catalyzed by titanium silicalite, such as for example  
the epoxidation of olefins (EP-100.119, the ammoxyma-  
tion of carbonyl compounds (US 4.794.198), the oxida-

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tion of ammonia to hydroxylamine (US 5.320.819) and the hydroxylation of aromatic hydrocarbons (US 4.369.783).

Generally solutions of hydrogen peroxide are used, obtained by synthesis processes which are based on the  
5 alternating oxidation and reduction of alkylanthraquinones.

These processes however, have substantial disadvantages deriving from the necessity of operating with large volumes of reagents, the numerous steps required,  
10 the relatively high cost of the intermediates and the production of inactive by-products.

As a result, other processes for the synthesis of hydrogen peroxide have been proposed in the art, among which those using a catalytic system consisting of a  
15 noble metal, preferably palladium, supported on a carrier, for the direct synthesis of hydrogen peroxide from hydrogen and oxygen.

For example, U.S. patent 4.772.458 describes a process for the synthesis of hydrogen peroxide which  
20 uses a catalyst based on palladium supported on coal, in which the reaction is carried out in water in the presence of hydrogen ions and bromide ions in a molar ratio of at least 2:1.

The  $H^+$  and  $Br^-$  ions are supplied as a combination  
25 of a strong acid such as sulfuric, phosphoric, hydro-

chloric or nitric acid, and a bromine salt.

Quantities of acid ranging from 2.5 to 10 g/litre are generally required to obtain high concentrations of  $\text{H}_2\text{O}_2$ .

5       The use of high quantities of acid, in addition to creating problems of a technological nature, for example corrosion of the autoclaves, also causes serious problems relating to the dissolution of the active phase (metal) of the catalyst in the reaction  
10 medium, with a consequent reduction in the activity and life of the catalyst itself.

The metal dissolved in the reaction medium, moreover, is difficult to recover with the recycling methods at present available.

15       In addition, the process operates under critical conditions as concentrations of  $\text{H}_2 > 5\%$  (generally 18%) with respect to the reaction mixture, are used, which is therefore within the explosivity limits of  $\text{H}_2/\text{O}_2$  mixtures.

20       U.S. patent 4.889.705 relates to an improved process for the synthesis of hydrogen peroxide in which the  $\text{H}^+$  and  $\text{Br}^-$  ions are supplied directly as  $\text{HBr}$ . Operating according to this process quantities of  $\text{Br}^-$  ions of more than  $10^{-4}$  moles/litre are required to  
25 obtain hydrogen peroxide. The use of high quantities of

halides creates problems of instability of both the catalyst metal and the hydrogen peroxide solution produced.

To overcome these drawbacks alternative processes have been proposed which can be carried out without acids and/or bromine ions in the reaction medium.

For example, patent application EP-492.064 describes a process for the synthesis of hydrogen peroxide from hydrogen and oxygen, which uses a catalyst based on palladium supported on a halogenated resin, in particular a brominated styrene/divinylbenzene resin.

The reaction is carried out in water, in the presence of an acid selected from sulfuric, phosphoric or nitric acid. Operating with this process however, concentrations of  $H_2O_2$  of about 0.58% are obtained.

EP-504741 describes a process for the synthesis of  $H_2O_2$  from hydrogen and oxygen which uses a catalyst based on palladium or platinum supported on an acid or superacid carrier selected from molybden, zirconium or tungsten oxides.

The reaction is carried out in water, in the presence of a promoter selected from bromine salts in quantities of more than 0.1 mmol/l of reaction mixture. Operating according to this process hydrogen peroxide is obtained in concentrations not higher

than 1%.

U.S. patent 5.320.921 describes a process for the synthesis of  $\text{H}_2\text{O}_2$  from hydrogen and oxygen which uses a catalyst based on palladium or platinum supported on a  
5 heteropolyacid made insoluble in water. The reaction is carried out in water in the presence of bromine ions (0.5 mmoles/litre of sodium bromide). Quantities of  $\text{H}_2\text{O}_2$  equal to about 1.1% are obtained.

These processes of the known art, therefore, do  
10 not have a productivity, referring to the quantity of hydrogen peroxide produced, which is sufficiently high for their application on an industrial scale to be of interest.

There is consequently an evident necessity for  
15 further improvements in the field of the production of hydrogen peroxide.

It has now been found that it is possible to satisfy these demands of the known art by means of a simple and convenient process which is based on the use  
20 of a catalyst consisting of a metal of group VIII supported on acid activated carbon functionalized with sulfonic groups.

The use of functionalized activated carbon containing the acid function directly bound to the surface  
25 and not released in the reaction medium has significant

advantages, in particular:

- (i) the possibility of using extremely low quantities of halides ( $< 10^{-4}$  moles/litre);
- (ii) the possibility of operating without free acids or  
5 in the presence of traces of free acids ( $H^+ < 10^{-4}$  moles/l);
- (iii) the production of a stable catalyst; the quantity of noble metal in solution is less than 3 parts per billion (ppb);
- 10 (iv) the production of stable solutions of hydrogen peroxide;
- (v) the production of solutions of hydrogen peroxide in high concentrations.

This is an advantage for subsequent uses of  $H_2O_2$  in  
15 oxidation processes, as intermediate processing operations such as, for example, the removal of solvents, are not required. In particular, the concentration of hydrogen peroxide which can be obtained with the process of the present invention is highly compatible  
20 with a direct use in oxidation reactions catalyzed by titanium-silicalite, without requiring concentration steps.

The presence of only traces of halides and acidity is not a disadvantage for direct use in the above  
25 reactions, as the possible introduction of salts or

acidity in downstream processes is minimized.

In accordance with this, a first aspect of the present invention relates to a catalyst consisting of a metal of group VIII supported on an acid activated  
5 carbon functionalized with sulfonic groups.

A further object of the present invention relates to a method for the preparation of an activated carbon functionalized with sulfonic groups.

The present invention also relates to an activated  
10 carbon functionalized with sulfonic groups and its use as a carrier for catalysts based on metals.

Yet another object of the present invention relates to a process for the production of hydrogen peroxide starting from hydrogen and oxygen, in a  
15 solvent; in the presence of a promoter and a catalytic system consisting of a metal of group VIII supported on a carrier, characterized in that said carrier is an activated carbon functionalized with sulfonic groups.

The present invention additionally relates to the  
20 use of solutions of hydrogen peroxide obtained as described above in an oxidation process catalyzed by titanium-silicalite.

Further objects of the present invention are evident in the following description and claims.

25 Examples of activated carbon which can be used for

the purposes of the present invention can be selected from activated carbon available on the market with a surface area of at least 100 m<sup>2</sup>/g.

Activated carbon with a surface area higher than  
5 300 m<sup>2</sup>/g is preferably used.

The activated carbon used can be in the form of powder, granules, pellets, etc.

The activated carbon can be used as such or it is pretreated by washing with a diluted solution, generally  
10 ly between 1 and 10% by weight, of aqueous hydrochloric acid, at 50-80°C.

The functionalization is carried out with a sulfonating agent preferably selected from sulfuric acid, SO<sub>3</sub> or oleum.

15 The functionalization of activated carbon is generally carried out using a weight ratio sulfonating agent:activated carbon ranging from 1:20 to 20:1, preferably between 1:5 and 5:1.

The functionalization reaction is carried out at  
20 a temperature ranging from 50°C to 350°C, preferably from 70°C to 200°C, for a period of time selected in relation to the temperature and sulfonating agent.

The activated carbon thus treated is then washed with water until neutrality of the washing water. The  
25 functionalized activated carbon is subsequently treated

with an oxidating agent. A diluted aqueous solution of  $\text{H}_2\text{O}_2$  (1-4% by weight) is preferably used, with a weight ratio sulfonated carbon: $\text{H}_2\text{O}_2$  solution ranging from 1:10 to 1:100, preferably between 1:20 and 1:50.

5        The resulting suspension is maintained, under stirring, at a temperature ranging from 30 to 100°C, preferably from 50 to 70°C, for a period of time ranging from 1 to 4 hours. It is then filtered, washed until the disappearance of the oxidating agent in the  
10 washing water and is then dried at a temperature ranging from 100°C to 120°C.

      The characterization of the functionalized activated carbon by means of photoelectron spectroscopy (XPS) reveals the presence of a peak characteristic of  
15 C-SO<sub>3</sub>H groups.

      This method is capable of providing information on the chemical species present on the surface of a solid sample (within 5 nm approx.), on the oxidation states of a certain element, and also on the ligands of a  
20 particular atom, in fact the position of the signal is determined by the electronic exchange with the environment.

      The sensitivity limit for sulfur can be estimated at about 50 ppm in the volume analyzed (1257 microns<sup>2</sup> x  
25 5 nm). The analysis is carried out in ultra high vacuum

(UHV) ( $10^{-10}$  Torr) and consequently the species physically adsorbed on the surface are eliminated and the essentially chemically bound species are analyzed.

As the samples are good electric conductors, the analysis is not affected by problems of surface electrostatic charge. The peak positions recorded on the axis of the "Binding Energies" are therefore not influenced by error, as they have been calibrated with an appropriate internal standard.

10        Semi-quantitative analysis (atomic %) provides the atomic concentrations of all the elements present above the sensitivity limit except for hydrogen which cannot be determined.

High resolution analysis of the sulfur signal (S) gives indications on the relative chemical environment.

Figures 1 and 2 show the enlarged peak of sulfur alone. It can be observed that the sulfur of the sample of sulfonated activated carbon is symmetrical with an enlargement of about 3 eV (Binding energy); this indicates the presence of a univocal but energetically heterogeneous species on the surface. The position in energy of the peak maximum ( $168.4 \pm 0.2$  eV), compared with the data supplied by the reference handbook (Handbook of XPS, ed J. Chastain, PE Corporation, MO  
25    USA, 1992, pages 60-61) unequivocally indicates the

presence of a sulfur species of the sulfonic type  
(-SO<sub>2</sub>OH) which is expected between 167-169 eV. This  
species cannot be confused with sulfur of the sulfide  
type (161-163 eV), or with sulfur of the sulfate type  
5 (169-171 eV).

Operating as described in the experimental exam-  
ples below, functionalized activated carbon is obtained  
with a sulfur content of 0.3 to 0.5% by weight with  
respect to the carrier.

10 However, lower or higher quantities than these  
values can be introduced depending on the starting  
carrier and operating conditions.

Quantities of sulfur ranging from 0.1 to 1.0% by  
weight are sufficient for the purposes of the present  
15 invention.

The catalyst of the present invention is prepared  
by supporting a metal of group VIII on activated carbon  
functionalized as described above.

Non-limiting examples of metals of group VIII are  
20 selected from palladium, platinum, ruthenium, iridium,  
rhodium or combinations of these. Palladium or platinum  
are preferably used. Palladium is particularly pre-  
ferred.

The quantity of metal supported on functionalized  
25 activated carbon is between 0.05 and 5% by weight,

preferably between 0.1 and 1% by weight.

The preparation of the catalyst of the present invention can be carried out by means of impregnation or adsorption of a soluble salt of the metal, optionally followed by a reduction phase of the metal with hydrogen or chemical reducing agents, according to the conventional techniques.

Metal salts selected from acetates, halides and oxalates are preferably used.

10 The catalyst of the present invention is particularly advantageous in a process for the direct preparation of hydrogen peroxide from hydrogen and oxygen in a solvent in the presence of a promoter selected from halogenated compounds.

15 The catalyst is used in catalytic quantities generally ranging from  $10^{-6}$  to  $10^{-2}$  moles of metal contained in the catalyst per litre of reaction medium.

Advantageous results are obtained using quantities of catalyst ranging from  $10^{-4}$  to  $10^{-3}$  moles of metal  
20 contained in the catalyst per litre of reaction medium.

The reaction solvent is selected from water, alcohols, or mixtures of these.

Examples of alcohols are methyl, ethyl, isopropyl alcohol. Methyl alcohol is preferred.

25 A mixture of water:alcohol with a weight ratio

ranging from 99/1 to 1/99, preferably between 90/10 and 5/95 is preferably used.

Examples of promoters are selected from compounds of bromine such as hydrobromic acid, sodium bromide, 5 potassium bromide, sodium bromate or ammonium bromide or compounds of chlorine such as sodium chloride, potassium chloride, ammonium chloride.

Compounds of bromine are preferred for the purposes of the present invention. Particularly preferred are 10 hydrobromic acid, sodium bromide and potassium bromide.

A quantity of promoter is normally used which is such as to give a concentration of halide ion of more than  $10^{-7}$  moles per litre of reaction medium, preferably a concentration ranging from  $10^{-6}$  to  $10^{-4}$  moles per litre 15 of reaction medium.

The production of hydrogen peroxide is effected by reacting oxygen and hydrogen in the reaction medium in the presence of the catalyst and promoter and with or without an inert gas (for example nitrogen), generally 20 at a total pressure higher than atmospheric pressure and preferably between 50 and 300 atmospheres.

The molar ratio  $H_2/O_2$  is between 1/1 and 1/100, preferably between 1/5 and 1/50 and the concentration of hydrogen in the gaseous phase in contact with the 25 liquid reaction medium is conveniently maintained at a

value of less than 4.5% molar with respect to the reaction mixture, outside the explosivity limits of the  $H_2/O_2$  mixture.

According to an embodiment of the present invention, the reaction can be carried out using air instead of pure oxygen.

The reaction is typically carried out at temperatures ranging from 0° to 90°C, preferably between 15 and 50°C.

At the end of the reaction, the solution containing hydrogen peroxide is recovered and the catalyst is separated and recovered by filtration and recycled to the subsequent reaction.

The process of the present invention can be carried out in batch or in continuous according to the conventional techniques.

The resulting solution of hydrogen peroxide can be used as such. However, if necessary it can be subjected to concentration operations to remove the solvent by distillation.

The process of the present invention enables the reagents to be transformed into  $H_2O_2$  with high conversions and selectivities, obtaining solution of  $H_2O_2$  without acidity or containing only traces of acidity and salts.

The solutions of hydrogen peroxide thus obtained can be used directly in oxidation processes which involve the use of  $H_2O_2$  without complex intermediate processing operations such as the removal of acids and  
5 solvents.

In particular, the hydrogen peroxide solutions obtained with the process of the present invention can be used directly in oxidation processes catalyzed by titanium silicalite as described in the patents cited  
10 above, as they are highly compatible with the optimum reaction conditions in which these processes are carried out with respect to:

- the concentration of  $H_2O_2$  in the solution;
- the absence of acidity or the presence of only traces  
15 of acidity or salts;
- the composition of the solvent medium consisting of water, alcohols or their mixtures in a wide range of ratios.

The use of hydrogen peroxide solutions in oxidation processes comprises the following steps:  
20

- (a) preparing hydrogen peroxide by the reaction of hydrogen and oxygen in a solvent containing a promoter, in the presence of a catalyst consisting of a metal of group VIII supported on acid activated carbon functionalized with sulfonic groups;  
25

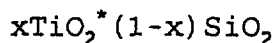
- (b) recovering the reaction mixture containing hydrogen peroxide;
- (c) putting the reaction mixture containing  $H_2O_2$  in contact with a substrate selected from olefins, aromatic hydrocarbons, ammonia and carbonyl compounds, in the presence of a catalyst based on titanium-silicalite to obtain the desired oxidated product;
- (d) recovering the oxidated product from the reaction mixture of step c); and
- 10 (e) recycling the possible non-reacted substrate in step c) and the reaction solvent in steps a) and c).

Examples of titanium-silicalites which can be used for the purposes of the present invention can be selected from titanium-silicalites with an MFI structure described in the U.S. patent 4.410.501, or the same titanium-silicalites modified with trivalent metals such as, for example, aluminum, iron, boron or gallium. The latter are described in European patents 226.257, 226.258 and 266.825.

20 Titanium-silicalites with an MEL or intermediate MFI/MEL structure described in Belgian patent 1.001.038, can also be used.

The preferred catalyst according to the present invention is titanium-silicalite having the formula:

25



wherein x represents a number between 0.0001 and 0.04.

The above titanium silicalites can be prepared according to the method described in the U.S. patent 4.410.501 in which their structural characteristics are  
5 also specified.

The quantity of catalyst used as well as the reaction conditions are selected in relation to the substrate to be oxidated.

In particular, the epoxidation of olefins can be  
10 carried out as described in the patent EP-100.119. The use of a hydro-alcoholic solution of hydrogen peroxide obtained with the process of the present invention advantageously allows in the epoxidation of olefins an improvement in the selectivity, at the same time  
15 simplifying the process operations owing to the substantial absence of acidity and/or salts which, in high concentrations, interfere with epoxidation reactions. In fact, a solution of hydrogen peroxide is obtained with only traces of acidity (pH about 4-6, higher than  
20 that of commercial hydrogen peroxide) and without stabilizers.

In the case of an ammoxymation process, (cyclohexanoneoxime from cyclohexanone,  $H_2O_2$ , ammonia), the use of a methanol solution of hydrogen peroxide,  
25 instead of terbutanol (TBA), allows a simplification in

the separation section of cyclohexanoneoxime and recycling of the solvent (methanol) as, unlike TBA, it does not form an azeotropic mixture with water.

The following examples, whose purpose is to describe the present invention in better detail, should in no way be interpreted as limiting the scope of the invention itself.

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#### EXAMPLE 1

##### 10 Functionalization of carbon

20 g of activated maritime pinewood carbon in powder form (CECA) are charged into a 1 litre glass flask containing 600 ml of an aqueous solution of HCl at 5% by weight. The stirred suspension is brought to 15 80°C and maintained at this temperature for 2.5 hours. After cooling to room temperature (20-25°C), the suspension is filtered and the carbon recovered is washed with distilled water until elimination of the chlorides and dried in an oven at 120°C for 2 hours.

20 The activated carbon is charged into a 250 ml glass flask and 40 ml of H<sub>2</sub>SO<sub>4</sub> at 96% are slowly added (in about 2-3 minutes). The carbon-acid mixture is homogenized and then heated in an oil bath to 120°C for 8 hours. At the end of the reaction, it is cooled to 25 room temperature and the activated carbon thus treated

is slowly poured into a 1 litre glass containing 500 ml of distilled water. The carbon is then recovered by filtration and washed with distilled water until neutrality of the washing water.

5       The activated carbon thus treated is suspended in 150 ml of an aqueous solution of  $H_2O_2$  (3.5% by weight) and the resulting suspension is maintained, under stirring, at 70°C for 2 hours. It is then filtered and washed until the disappearance of  $H_2O_2$  in the washing  
10 water. The sulfonated activated carbon is recovered and dried in an oven at 120°C for 2 hours.

Characterization by means of X-ray induced photoelectron spectroscopy (XPS) shows the presence of a peak relating to the signal C-SO<sub>3</sub>H (figure 1).

15       The results expressed in atomic % from XPS analysis are indicated in table 1.

Table 1

| =====   |       |       |       |      |      |       |
|---------|-------|-------|-------|------|------|-------|
| Sample  | C     | O     | S     | Cl   | Si   | Na    |
| 20    1 | 88.7% | 10.7% | 0.12% | 0.3% | 0.1% | 0.06% |
| =====   |       |       |       |      |      |       |

Elemental characterization was carried out on the sample of sulfonated carbon (Nr. 1). The results, expressed in mg/kg, are indicated in table 3 and show  
25 a sulfur content of 0.39% by weight.

EXAMPLE 2Functionalization of carbon

The same procedure is adopted as in example 1, but carrying out the sulfonation reaction at a temperature of 140°C for 4 hours.

Characterization by means of X-ray induced photoelectron spectroscopy (XPS) shows the presence of a peak relating to the signal C-SO<sub>3</sub>H (figure 2)

The results expressed in atomic % from XPS analysis are indicated in table 2.

Table 2

| =====  |       |      |       |      |      |       |
|--------|-------|------|-------|------|------|-------|
| Sample | C     | O    | S     | Cl   | Si   | Na    |
| 2      | 90.3% | 9.1% | 0.14% | 0.3% | 0.1% | 0.08% |
| =====  |       |      |       |      |      |       |

Elemental characterization was carried out on the sample of sulfonated carbon (Nr. 2). The results, expressed in mg/kg, are indicated in table 3 and show a sulfur content of 0.48% by weight.

20 EXAMPLE 3Preparation of the catalyst

50 ml of methanol and 4 g of activated carbon prepared as described in example 1 are charged into a 250 ml glass flask.

25 A solution of palladium acetate in acetone (86 mg

palladium acetate 98% Aldrich, in 20 ml of acetone) are added dropwise in 2-3 minutes to the stirred suspension. The solution is concentrated with a rotovapor on a bath at 40-50°C, for 10-20 minutes to remove about 5 30-50% of the solvent. It is filtered with a pump, washed with water, dried in air and then dried in an oven at 110°C for 2 hours. A catalyst is obtained containing 1% of palladium on functionalized activated carbon.

10 EXAMPLE 4

Preparation of the catalyst

The same procedure is adopted as in example 3, but using 4 g of activated carbon prepared as described in example 2. A catalyst is obtained containing 1% of 15 Palladium on functionalized activated carbon.

EXAMPLE 5 (comparative)

A catalyst is prepared as described in example 3, but using a non-sulfonated activated maritime pinewood carbon in powder form (CECA).

20 EXAMPLE 6

Preparation of hydrogen peroxide

23 mg of catalyst prepared as described in example 4 ( $2 \cdot 10^{-6}$  moles of Pd) and 9 g of a solution of water: methanol (weight ratio 1:8), containing 6 ppm of HBr 25 ( $6 \cdot 10^{-5}$  moles Br<sup>-</sup>/litre reaction mixture) are charged

into a 100 ml AISI 316 stainless steel autoclave, equipped with a cylindrical glass container, teflon magnetic stirrer, manometer and heat-exchange apparatus.

5       The autoclave is thermostat-regulated at 30°C, closed and then charged with a mixture of gases, previously prepared, consisting of 4% volume  $H_2$ , 4% volume  $O_2$  and 92% volume  $N_2$ , at a total pressure of 65 atm. Stirring is carried out at 900 revs/minute for 1  
10 hour substituting the gas phase every 15 minutes with a mixture of gases having the above composition.

The autoclave is then depressurized, the content is filtered to remove the catalyst and an aliquot of the solution is analyzed by titration with potassium  
15 permanganate to determine the concentration of hydrogen peroxide, which proves to be equal to 2.9% by weight with respect to the reaction mixture.

From the increase in weight of the solution and concentration of  $H_2O_2$ , the selectivity with respect to  
20 the converted hydrogen is 50%.

#### EXAMPLE 7

##### Synthesis of hydrogen peroxide

The reaction is carried out under the same operating conditions indicated in example 6, but using 23 mg  
25 of catalyst prepared as described in example 4. A

solution is obtained, containing 3.1% by weight of hydrogen peroxide. From the increase in weight of the solution, the selectivity with respect to the converted hydrogen is 58%.

5 EXAMPLE 8 (comparative)

The reaction is carried out under the same operating conditions indicated in example 6, but using 23 mg of catalyst prepared as described in example 5. A solution is obtained with a content by weight of  
10 hydrogen-peroxide equal to 0.25%. The selectivity with respect to the converted hydrogen is 7%.

EXAMPLE 9

Preparation in continuous of hydrogen peroxide

The experimentation is carried out in a 300 ml  
15 Hastelloy C steel autoclave, equipped with a magnetic stirrer capable of maintaining the number of revs/minute during the test from 0 to 2000, a pressure controller, a thermostatic jacket and gas-flow controllers.

20 0.45 g of catalyst prepared as described in example 4 ( $4.2 \cdot 10^{-5}$  moles of Pd) and 150 g of water containing 4 ppm of HBr ( $5 \cdot 10^{-5}$  moles of Br<sup>-</sup>/litre of reaction mixture) are charged into this autoclave.

The autoclave is pressurized, without stirring, to  
25 100 atm with a gaseous mixture consisting of 3.6%

volume  $H_2$ , 46.4% volume  $O_2$  and 50% volume of  $N_2$ . The stirring is then activated up to 1400 revs/minute and the pressure is maintained at 100 atm with a gas flow in continuous equal to 300 l/hour.

5        The reaction is followed by gaschromatographic analysis of aliquots of the gaseous phase leaving the reactor every 15 minutes.

During the test, the conversion of hydrogen is maintained constant (45%).

10       After 4 hours of reaction at 18°C, the concentration of  $H_2O_2$  is equal to 12.5% by weight. The selectivity with respect to the converted hydrogen is equal to 60%.

The content of  $SO_4^{--}$  ion in solution is equal to 3 ppm.

15    EXAMPLE 10

The same procedure is adopted as in example 9, but using as reaction medium 150 g of a mixture of water:methanol with a weight ratio 10:90, containing 3 ppm of HBr ( $3 \cdot 10^{-5}$  moles  $Br^-$ /litre of reaction mixture).

20       The production of hydrogen peroxide is carried out at 15°C. The conversion of hydrogen remains constant during the test at 80%.

After 2 hours of reaction, the concentration of  $H_2O_2$  was equal to 13.1% by weight. The selectivity with  
25    respect to the converted hydrogen is 75%.

The content of  $\text{SO}_4^{--}$  ion in solution is equal to 2.5 ppm.

#### EXAMPLE 11

A 380 ml Hastelloy C steel autoclave is used, 5 equipped with a magnetic stirrer, a pressure controller, therostatic jacket and gas-flow controllers.

0.60 g of catalyst prepared as described in example 3 ( $5.6 \cdot 10^{-5}$  moles of Pd) and 200 g of water containing 5 ppm of HBr ( $6.2 \cdot 10^{-5}$  moles of  $\text{Br}^-$ /litre of 10 reaction mixture) are charged into the autoclave.

The autoclave is pressurized, without stirring, to 95 atm with a gaseous mixture consisting of 3.6% volume  $\text{H}_2$ , 36.4% volume  $\text{O}_2$  and 60% volume of  $\text{N}_2$ . The stirring is then activated up to 1400 revs/minute and the 15 pressure is maintained with a flow in continuous of the same gaseous mixture.

During the test 120 g/hour of an aqueous solution containing 5 ppm of HBr are fed in continuous and volumes of liquid necessary for keeping the level of 20 the autoclave constant, are discharged. The reaction is carried out at  $25^\circ\text{C}$  for 8 hours.

The reaction is followed by gaschromatographic analysis of aliquots of the gaseous phase leaving the reactor every 15 minutes and the liquid phase every 25 hour.

During the test, the conversion of hydrogen is maintained constant at 85%.

After 4 hours of reaction, the concentration of  $\text{H}_2\text{O}_2$  is equal to 6.5% by weight. The selectivity with respect to the converted hydrogen is equal to 60%. The content of  $\text{SO}_4^{--}$  ion in solution is equal to 2 ppm.

After 8 hours of reaction the concentration of  $\text{H}_2\text{O}_2$  and the selectivity with respect to the converted hydrogen remain constant at 6.5% and 60% respectively and the content of  $\text{SO}_4^{--}$  ion in solution is less than 1 ppm.

#### EXAMPLE 12

The same procedure is adopted as in example 11, but using as reaction medium a mixture of water: methanol with a weight ratio of 4:96, a reaction temperature of 20°C and feeding in continuous 200 g/hour of water:methanol mixture.

The hydrogen conversion is maintained constant during the test at a value equal to 85%.

In the sampling carried out after 4 hours of reaction, the concentration of hydrogen peroxide in solution is equal to 5.8% by weight. This value remains constant for the whole duration of the test which lasts 20 hours. The selectivity with respect to the hydrogen is 84%. The concentration of  $\text{SO}_4^{--}$  ion in solution after

20 hours is less than 1 ppm.

#### EXAMPLE 13

The same procedure is adopted as in example 12, using the catalyst prepared as in example 4 and prolonging the reaction for 60 hours.

After 60 hours of reaction the hydrogen conversion is maintained constant at a value equal to 88%, the concentration of  $\text{H}_2\text{O}_2$  is maintained at 6.2% by weight and the selectivity with respect to the hydrogen is 86%. The concentration of  $\text{SO}_4^{--}$  ion in the reaction effluent from the thirtieth hour is zero.

#### EXAMPLE 14

##### Oxidation of propylene

5 g of titanium silicalite TS-1 (EniChem, with a content of titanium equal to 2.05% by weight) in 500 g of methanol are suspended in a 1 l reactor equipped with a mechanical stirrer with a gaseous effect and a thermostatic system (internal coil immersed in the reaction solution and external circulation jacket).

After thermostat-regulating the system at 40°C and pressurizing with propylene at 1.2 atm (constant for the whole duration of the reaction), 266 g of hydrogen peroxide solution at 6.22%, obtained as described in example 13, are added in continuous at such a rate as to exhaust the addition of the oxidating agent in 15

minutes.

After this period a sample of reaction solution is taken.

The residual  $H_2O_2$  is determined iodometrically,  
5 whereas the reaction product is quantified by gaschromatography. The results are:

conversion  $H_2O_2$  = 96%

selectivity to propylene oxide = 97%.

#### EXAMPLE 15

##### 10 Amoxymation of cyclohexanone

10 g of titanium silicalite TS-1 (EniChem, with a content of titanium equal to 2.05% by weight) in 500 g of a mixture consisting of:

- methanol 41% by weight
- 15 - water 31% by weight
- cyclohexanone 20% by weight
- ammonia 8% by weight

are suspended in a 1 l reactor equipped with a mechanical stirrer with a gaseous effect and a thermostatic  
20 system (internal coil immersed in the reaction solution and external circulation jacket).

After thermostat-regulating the system at 80°C and pressurizing with helium at 1.5 atm, 67.5 g of the  $H_2O_2$  solution (6.22%) obtained in example 13 are added in  
25 continuous in 5 hours.

After this period a sample of reaction solution is taken.

The residual  $\text{H}_2\text{O}_2$  is determined iodometrically, whereas the reaction product is quantified by gaschromatography. The results are:

conversion of cyclohexanone = 92.5%

selectivity to cyclohexanone = 96%.

The conversion of hydrogen peroxide is quantitative.

Table 3

| Elements | CECA carbon as such | Carbon # 1 | Carbon # 2 |
|----------|---------------------|------------|------------|
| B        | 20                  | < 1        | < 1        |
| Na       | 200                 | 17         | 20         |
| Mg       | 2,000               | 47         | 47         |
| Al       | 350                 | 60         | 100        |
| Si (1)   | 300                 | 400        | 380        |
| P        | 1,300               | 57         | 64         |
| S (1)    | 200                 | 3,900      | 4,800      |
| Cl (1)   | 100                 | < 100      | < 100      |
| K        | 3,800               | 68         | 90         |
| Ca       | 6,800               | 90         | 80         |
| Ti       | 3                   | < 1        | < 1        |
| Cr       | 1                   | < 1        | < 1        |
| Mn       | 215                 | 4          | 4          |
| Fe       | 140                 | 30         | 17         |
| Co       | < 1                 | < 1        | < 1        |
| Ni       | < 1                 | < 1        | < 1        |
| Cu       | 5                   | 2          | 8          |
| Zn       | 3                   | 8          | 3          |
| Rb       | 8                   | < 1        | < 1        |
| Sr       | 17                  | < 1        | < 1        |
| Nb       | < 1                 | < 1        | < 1        |
| Mo       | 1                   | 2          | < 1        |
| Pd       | < 1                 | < 1        | < 1        |
| Ag       | < 1                 | < 1        | < 1        |
| Ba       | 11                  | < 1        | < 1        |
| Ta       | < 1                 | < 1        | < 1        |
| Hg (2)   | 0.11                | 1.3        | 1.3        |
| Pb       | < 1                 | < 1        | < 1        |
| others   | < 1                 | < 1        | < 1        |

CLAIMS

1. A catalyst which can be used for the direct synthesis of hydrogen peroxide starting from hydrogen and oxygen consisting of a metal belonging to group VIII supported on a carrier wherein said carrier is an acid activated carbon functionalized with sulfonic groups.
2. The catalyst according to claim 1, wherein the metal belonging to group VIII is selected from palladium, platinum, ruthenium, iridium, rhodium or combinations of these.
3. The catalyst according to claim 2, wherein the metal is palladium.
4. The catalyst according to claim 1, wherein the quantity of metal belonging to group VIII is between 0.05 and 5% by weight with respect to the carrier.
5. The catalyst according to claim 4, wherein the quantity of metal belonging to group VIII is between 0.1 and 1% by weight with respect to the carrier.
6. The catalyst according to claim 1, wherein the functionalized activated carbon contains from 0.1 to 1% by weight of sulfur.
7. The catalyst according to claim 1, obtained by a



method which comprises:

- 5 a) putting the activated carbon in contact with a sulfonating agent with a weight ratio sulfonating agent:carbon ranging from 1:20 to 20:1, at a temperature ranging from 50 to 350°C; and
- b) washing the functionalized activated carbon with water until neutrality of the washing water;
- 10 c) treating the sulfonated activated carbon obtained in step b) with an oxidating agent, at a temperature ranging from 30 to 100°C;
- d) washing the functionalized activated carbon obtained in step c) until the disappearance of the oxidating agent in the washing water and drying at a temperature of 100 to 120°C; and finally
- 15 e) supporting the metal of group VIII on activated carbon functionalized with sulfonic groups.
8. The catalyst according to claim 7, wherein step a) is preceded by a step a') wherein the activated carbon is washed with an aqueous solution of
- 20 hydrochloric acid 1-5% by weight, at a temperature ranging from 50 to 80°C.
9. The catalyst according to claim 7, wherein in step a) the weight ratio sulfonating agent:carbon is between 1:5 and 5:1, the temperature varies from
- 25 70 to 200°C.



10. The catalyst according to claim 7, wherein the sulfonating agent is selected from sulfuric acid,  $\text{SO}_3$  and oleum.
11. The catalyst according to claim 7, wherein in step  
5 c) an aqueous solution of hydrogen peroxide is used at a concentration ranging from 1 to 4% by weight, with a weight ratio sulfonated activated carbon and aqueous solution of hydrogen peroxide ranging from 1:10 to 1:100.
- 10 12. The catalyst according to claim 11, wherein the weight ratio sulfonated activated carbon and aqueous solution of hydrogen peroxide is between 1:20 and 1:50.
13. The catalyst according to claim 7, wherein in step  
15 c) the temperature is between 50 and 70°C.
14. An acid activated carbon functionalized with sulfonic groups which can be used as carrier for metallic catalysts.
15. A process for the direct production of hydrogen  
20 peroxide by means of the reaction of hydrogen and oxygen in a solvent which contains a promoter in the presence of a catalyst consisting of a metal of group VIII supported on a carrier, wherein said carrier is an activated carbon functionalized with  
25 sulfonic groups.



16. The process according to claim 15, wherein the metallic catalyst of group VIII is selected from palladium, platinum, ruthenium, iridium, rhodium or combinations of these.
- 5 17. The process according to claim 16, wherein the metal is palladium.
18. The process according to claim 15, wherein the promoter is a compound containing a halogen.
19. The process according to claim 18, wherein the  
10 compound containing a halogen is selected from the group consisting of hydrobromic acid, sodium bromide, potassium bromide, sodium bromate or ammonium bromide or compounds of chlorine such as sodium chloride, potassium chloride, ammonium  
15 chloride.
20. The process according to claim 19, wherein the compound is hydrobromic acid, sodium bromide and potassium bromide.
21. The process according to claim 15, wherein a  
20 quantity of promoter is used which is such as to give a concentration of the halide ion of more than  $10^{-7}$  moles per litre of reaction medium.
22. The process according to claim 21, wherein a  
25 quantity of promoter is used which is such as to give a concentration of the halide ion between  $10^{-6}$



and  $10^{-4}$  moles per litre of reaction medium.

23. The process according to claim 15, wherein the reaction medium is selected from water, an alcohol or a mixture of these.
- 5 24. The process according to claim 23, wherein the alcohol is selected from methanol, ethanol, isopropanol.
25. The process according to claim 24, wherein the alcohol is methanol.
- 10 26. The process according to claim 15, wherein the reaction medium is a mixture of water:alcohol with a weight ratio between the two of 99:1 to 1:99.
27. The process according to claim 26, wherein the weight ratio water:alcohol is between 90:10 and
- 15 5:95.
28. The process according to claim 15, wherein the reaction is carried out at a temperature ranging from 0 to 70°C.
29. The process according to claim 28, wherein the
- 20 temperature is between 15 and 50°C.
30. The process according to claim 15, wherein the reaction is carried out at a total pressure higher than atmospheric pressure and with a molar ratio hydrogen:oxygen ranging from 1:1 to 1:100.
- 25 31. The process according to claim 30, wherein the



total pressure is between 50 and 300 atmospheres and the molar ratio hydrogen:oxygen is between 1:5 and 1:50.

32. The process according to claim 15, wherein the  
5 reaction is carried out using air as oxygen source.
33. The process according to claim 15, wherein the catalyst is used in quantities ranging from  $10^{-6}$  to  $10^{-2}$  moles of metal contained in the catalyst per  
10 litre of reaction medium.
34. The process according to claim 33, wherein the catalyst is used in quantities ranging from  $10^{-4}$  to  $10^{-3}$  moles of metal contained in the catalyst per litre of reaction medium.
- 15 35. A process for the catalytic oxidation of substrates which comprises:
- (a) preparing hydrogen peroxide by the reaction of hydrogen and oxygen in a solvent containing a promoter, in the presence of a catalyst consisting  
20 of a metal of group VIII supported on acid activated carbon functionalized with sulfonic groups;
- (b) recovering the reaction mixture containing hydrogen peroxide;
- (c) putting the reaction mixture containing  $H_2O_2$   
25 in contact with a substrate selected from olefins,



aromatic hydrocarbons, ammonia and carbonyl compounds, in the presence of a catalyst based on titanium-silicalite to obtain the desired oxidated product;

5 (d) recovering the oxidated product from the reaction mixture of step c); and

(e) recycling the possible non-reacted substrate in step c) and the reaction solvent in steps a) and c).

10 36. The process according to claim 35, wherein in step c) the catalyst is selected from titanium-silicalites with an MFI structure, titanium-silicalites with an MEL structure or intermediate MFI/MEL structure.

15 37. The process according to claim 36, wherein the titanium-silicalites with an MFI structure are modified with trivalent metals selected from aluminum, iron, boron or gallium.

20 38. The process according to claim 35, wherein the catalyst is titanium-silicalite having the formula:  
$$x\text{TiO}_2 \cdot (1-x)\text{SiO}_2$$
  
wherein x represents a number between 0.0001 and 0.04.

25 39. The process according to claim 35, wherein said process is carried out in continuous.

