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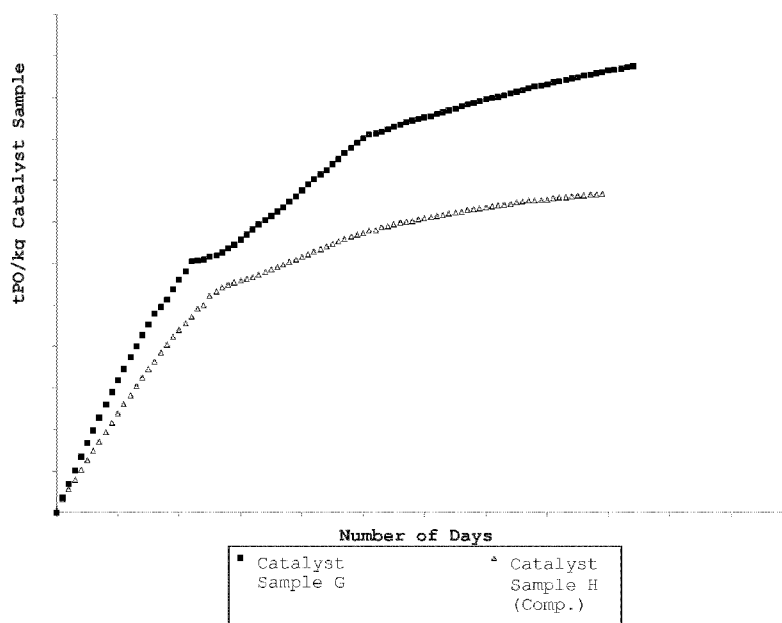
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(54) Title: CATALYST PREPARATION

Figure 1



(57) **Abstract**: Process for the preparation of an epoxidation catalyst, which process comprises: (a) drying a silica gel carrier having a surface area in the range of from 330 to 450 m²/g at a temperature in the range of from 300 to 450 °C, and (b) contacting the carrier obtained in step (a) with a gas stream containing titanium halide to obtain an impregnated carrier, and the use of such catalyst in the preparation of alkylene oxide.



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CATALYST PREPARATION

The present invention relates to the preparation of an epoxidation catalyst and to the process of preparing alkylene oxide utilising said catalyst.

Background of the Invention

5 An epoxidation catalyst is understood to be a catalyst which catalyses the manufacture of an epoxy group containing compound. A well known process comprises contacting organic hydroperoxide and alkene with a heterogeneous epoxidation catalyst and withdrawing a
10 product stream comprising alkylene oxide and an alcohol.

Catalysts for the manufacture of an epoxy group containing compound are well known.

EP 345856 A describes the preparation of an epoxidation catalyst comprising impregnating a silicium
15 compound with a stream of gaseous titanium tetrachloride preferably comprising an inert gas. In the example, it is mentioned that dried silica is used.

WO 2004/050233 A1 discloses a further improved process for the preparation of an epoxidation catalyst
20 comprising impregnating a silicon containing carrier with a gas stream consisting of titanium halide, wherein the resulting catalyst has improved selectivity even though the carrier has been in contact with the same amount of titanium halide.

25 US 6114552 A and US 6383966 B1 teach the use of a high surface area silica support or the like having a surface area greater than 1100 m²/g in preparing epoxidation catalysts. The high surface area solid is impregnated with either a solution of a titanium halide
30 in a non-oxygenated hydrocarbon solvent or a gas stream

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of titanium tetrachloride. It is mentioned that it is desirable to dry the silica support prior to impregnation, for example by heating for several hours at a temperature of at least 200 to 700 °C. The exemplified silica supports to be impregnated with gaseous titanium tetrachloride were dried at 450 °C in air.

US 5932751 A describes the preparation of titanium on silica catalysts in which the silica has been washed prior to the deposition of the titanium component thereon. A solution is used for depositing the titanium component.

US 2015/0182959 A1 discloses a process for the preparation of a titanium-based catalyst active in epoxidation reactions, which process comprises the steps of:

(a) Impregnating a silica carrier with a liquid solution of a titanium compound in an inorganic solvent system, to form an impregnated silica carrier bearing the solution of the titanium compound;

(b) drying the impregnated silica carrier obtained in step (a);

(c) calcining the product obtained in step (b) at a temperature of at most 750 °C; and

(d) silylating the product obtained in step (c), to give a titanium-based catalyst active in epoxidation reactions.

WO 2004/050241 A1 describes an epoxidation catalyst having improved selectivity, which catalyst is prepared by a process comprising:

(a) drying a silica gel carrier having a weight average particle size of from 0.1 to 2 millimetre at a temperature of from more than 200 to 300 °C, and

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(b) contacting the carrier obtained in step (a) with a gas stream containing titanium halide to obtain an impregnated carrier.

5 There has been continued interest in improving the epoxidation reactions in general, and more specifically the performance of catalysts for the preparation of alkylene oxide.

In particular, there is a desire to improve catalyst preparation by reducing the formation of catalyst fines.

10 Catalyst fines are catalyst particles that are typically smaller than 0.6 mm in weight average particle size. Such catalyst fines lead to a steep build-up of pressure drop across the catalyst bed in the commercial reactors. These fines also affect the isolation valves
15 downstream of the reactors by scratching the valve seat surface which prevents complete isolation of the reactors. Incomplete isolation is a process safety hazard. Thus, fines must therefore be removed before catalyst can be used. Hence, the formation of catalyst
20 fines leads to yield losses of alkylene oxide as some of the catalyst prepared must be discarded prior to use.

Furthermore, in addition to reducing the amount of catalyst fines, there is also a desire to further improve catalyst activity, leading to higher alkylene oxide
25 production.

Summary of the Invention

In the present invention, a process for the preparation of epoxidation catalyst has been surprisingly found which not only results in reduced formation of
30 catalyst fines, but also achieves a catalyst having advantageous activity and stability.

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Accordingly, the present invention provides a process for the preparation of an epoxidation catalyst, which process comprises:

(a) drying a silica gel carrier having a surface area in the range of from 330 to 450 m²/g at a temperature in the range of from 300 to 450 °C, and

(b) contacting the carrier obtained in step (a) with a gas stream containing titanium halide to obtain an impregnated carrier.

Brief Description of the Drawings

Figures 1 and 2 compare the performance of epoxidation catalyst made in accordance of the process of the present invention in a commercial reactor set up for the epoxidation of propylene to propylene oxide with the performance of a comparative sample of Ti catalyst typically used in the commercial epoxidation of propylene.

Detailed Description of the Invention

The catalyst of the present invention is obtained by drying of a silica gel carrier, and subsequent impregnation of the carrier. In principle, any silica gel carrier having a surface area in the range of from 330 to 450 m²/g is suitable for use in the preparation process according to the present invention.

As used herein, surface area is determined in accordance with the well known B.E.T. (Brunauer-Emmett-Teller) nitrogen adsorption technique, often simply termed the "B.E.T. method". Herein, the general procedure and guidance of ASTM D4365-95 is followed in the application of the "B.E.T. method" to the materials. "B.E.T. surface area" as used herein refers to the surface area of the silica gel carrier prior to impregnation with titanium.

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The silica gel carrier for use in the present invention preferably has a surface area in the range of from 340 to 450 m²/g, more preferably in the range of from 350 to 450 m²/g, even more preferably in the range of from 380 to 450 m²/g and most preferably in the range of from 400 to 450 m²/g, according to ASTM D4365-95.

It is known that contaminants can influence the performance of the final catalyst. It has been found that gas phase impregnation according to the present invention gives especially good results if the silica carrier contains at most 1200 ppm of sodium, more specifically at most 1000 ppm of sodium. Further, the silica carrier preferably comprises at most 500 ppm of aluminium, at most 500 ppm of calcium, at most 200 ppm of potassium, at most 100 ppm of magnesium and at most 100 ppm of iron.

The silica gel carrier for use in the present invention can in principle be any carrier having a surface area in the range of from 330 to 450 m²/g and which is derived from a silicon-containing gel. In general, silica gels are a solid, amorphous form of hydrous silicon dioxide distinguished from other hydrous silicon dioxides by their microporosity and hydroxylated surface. Silica gels usually contain three-dimensional networks of aggregated silica particles of colloidal dimensions. They are typically prepared by acidifying an aqueous sodium silicate solution to a pH of less than 11 by combining it with a strong mineral acid. The acidification causes the formation of monosilicic acid (Si(OH)₄), which polymerizes into particles with internal siloxane linkages and external silanol groups. At a certain pH, the polymer particles aggregate, thereby forming chains and ultimately gel networks. Silicate concentration, temperature, pH and the addition of

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coagulants affect gelling time and final gel characteristics such as density, strength, hardness, surface area and pore volume. The resulting hydrogel is typically washed free of electrolytes, dried and
5 activated.

In a preferred embodiment, the silica gel carrier for use in the present invention has a weight average particle size in the range of from 0.2 to 3.0 mm, more preferably in the range of from 0.4 to 2.5 mm and most
10 preferably in the range of from 0.7 to 2.0 mm.

Silica gel carriers that may be conveniently used in the present invention are commercially available from Grace, PQ Corp. and Kukdong.

Optionally, the silica gel carrier may be subjected
15 to a pre-treatment prior to step (a), said pre-treatment comprising calcining the silica gel carrier and subsequently hydrolysing the carrier obtained. Hydrolysis comprises treating the carrier with water or steam. Preferably, the hydrolysis is carried out with steam.

Alternatively, the hydrolysis treatment may comprise a
20 washing treatment using an aqueous solution of a mineral acid, an aqueous solution of an ammonium salt or a combination thereof. Any water which might still be present after hydrolysis is preferably removed before
25 treating the carrier further. Water is preferably removed by the drying of step (a). Preferably, the calcination is carried out at a relatively high temperature.

The preferred carrier pre-treatment prior to step (a) comprises (i) calcining the silica gel carrier at a
30 temperature of at least 400 °C and (ii) hydrolysing the calcined silica gel carrier. The hydrolysed calcined silica gel carrier of pre-treatment step (ii) may then be

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subjected to steps (a) and (b) of the process of the present invention.

Preferably, the calcination of pre-treatment step (i) is carried out at a temperature in the range of from 450 to 800 °C, more preferably in the range of from 500 to 700 °C.

It will be appreciated that if such a carrier pre-treatment is carried out, then step (a) of the process of the present invention is carried out on calcined and hydrolysed carrier.

The drying step (a) according to the present invention comprises subjecting silica gel carrier having a surface area in the range of from 330 to 450 m²/g, preferably in the range of from 340 to 450 m²/g, more preferably in the range of from 350 to 450 m²/g, even more preferably in the range of from 380 to 450 m²/g and most preferably in the range of from 400 to 450 m²/g, to a temperature in the range of from 300 to 450 °C.

The time period during which the drying is carried out strongly depends on the kind of silica gel used and whether there is any pre-treatment of the silica gel carrier according to optional steps (i) and (ii). However, the drying will generally be carried out for a period in the range of from 15 minutes up to 10 hours, more specifically in the range of from 1 to 8 hours, most specifically in the range of from 1 to 5 hours.

In a preferred embodiment of the present invention, the drying is carried out at a temperature in the range of from 340 to 450 °C, more preferably in the range of from 340 to 430 °C and most preferably in the range of from 360 to 400 °C.

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The atmosphere in which step (a) is performed is not limited and may be air, an oxygen-containing atmosphere, or an inert, oxygen-free, atmosphere.

5 However, in one embodiment of the present invention, step (a) may be conveniently performed in an oxygen-free atmosphere. In particular, the drying may be conveniently performed in an inert atmosphere comprising one or more of nitrogen, argon and helium. Said atmosphere preferably comprises less than 0.1 wt. % of oxygen. Most preferably, 10 said atmosphere is nitrogen.

It has been found in the present invention that silica gel carrier having a surface area in the range of from 340 to 450 m²/g, preferably in the range of from 350 to 450 m²/g, more preferably in the range of from 380 to 15 450 m²/g and most preferably in the range of from 400 to 450 m²/g, which had been dried in this way gave rise to a catalyst upon impregnation with gaseous titanium halide having advantageous activity and reduced formation of catalyst fines.

20 A preferred preparation method further comprises that the drying of step (a) is carried out at a temperature which is higher than the temperature at which the impregnation of step (b) is carried out. Such drying ensures that there is no substantial amount of water 25 present during impregnation of the silica gel carrier with titanium halide. This prevents that a substantial amount of the titanium halide reacts with water. Reaction between titanium halide and water makes that titanium compounds are formed which do not contribute to 30 catalysing the epoxidation reaction such as titanium oxide.

The impregnation temperature of step (b) is the temperature of the silica gel carrier before being

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brought into contact with the gaseous titanium halide. When the silica gel carrier is reacting with the titanium halide, the temperature of the carrier increases due to the exothermic nature of the reaction.

5 A further preferred embodiment of the process of the present invention comprises supplying an amount of titanium halide in step (b) which is such that the molar ratio of titanium halide added to silicon present in the carrier is in the range of from 0.050 to 0.063.

10 Generally in step (b), the silica gel carrier is contacted with the titanium halide for a period in the range of from 0.1 to 10 hours, more specifically in the range of from 0.5 to 6 hours. Preferably, at least 30 wt. % of the titanium is added during the first 50 % of the
15 impregnation time. The time of impregnation is taken to be the time during which the silica gel carrier is in contact with gaseous titanium halide. Most preferably, the silica gel carrier is contacted with a similar amount of titanium halide during the full time of the
20 impregnation. However, it will be clear to someone skilled in the art that deviations from this are allowable such as at the start of the impregnation, at the end of the impregnation and for relatively short time intervals during impregnation.

25 Titanium halides which may be conveniently used comprise tri- and tetra-substituted titanium complexes which have in the range of from 1 to 4 halide substituents with the remainder of the substituents, if any, being alkoxide or amino groups. The titanium halide
30 can be either a single titanium halide compound or can be a mixture of titanium halide compounds. Preferably, the titanium halide comprises at least 50 wt. % of titanium tetrachloride, more specifically at least 70 wt. % of

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titanium tetrachloride. Most preferably, the titanium halide is titanium tetrachloride.

The present invention comprises the use of a gas stream comprising titanium halide in step (b).

5 Preferably, the gas stream consists of titanium halide, optionally in combination with an inert gas. If an inert gas is present, the inert gas preferably is nitrogen. Especially selective catalysts may be obtainable with the help of a gas stream solely consisting of titanium
10 halide. In such a process, the preparation is carried out in the absence of a carrier gas. However, limited amounts of further gaseous compounds are allowed to be present during the contact between the silica gel carrier and the gaseous titanium halide. The gas in contact with the
15 carrier during impregnation preferably consists for at least 70 wt. % of titanium halide, more specifically at least 80 wt. %, more specifically at least 90 wt. %, most specifically at least 95 wt. %. Specific preferred processes have been described in WO 2004/050233 A1.

20 Gaseous titanium halide can be prepared in any way known to someone skilled in the art. A simple and easy way comprises heating a vessel containing titanium halide to such temperature that gaseous titanium halide is obtained. If inert gas is to be present, the inert gas
25 can be fed over the heated titanium halide.

After steps (a) and (b) of the present invention, the impregnated carrier may be further treated before being used as a catalyst.

30 In a preferred embodiment of the present invention, after steps (a) and (b), the impregnated carrier will be calcined, subsequently hydrolysed and optionally silylated before being used as a catalyst.

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Therefore, in a preferred embodiment, the present invention provides a process further comprising:

(c) calcining the impregnated carrier obtained in step (b);

5 (d) hydrolysing the calcined impregnated carrier of step (c); and, optionally,

(e) contacting the carrier obtained in step (d) with a silylating agent.

10 It is believed that calcination removes hydrogen halide, more specifically hydrogen chloride which is formed upon reaction of titanium halide and silicon compounds present on the surface of the silicon containing carrier.

The optional calcination in step (c) of the
15 impregnated carrier generally comprises subjecting the impregnated carrier to a temperature of at least 500 °C, more specifically at least 600 °C. Preferably, the calcination is carried out at a temperature of at least 650 °C. From a practical point of view, it is preferred
20 that the calcination temperature applied is at most 1000 °C, more preferably at most 700 °C.

Hydrolysis of the impregnated and calcined carrier can remove remaining Ti-halide bonds. The hydrolysis of the impregnated carrier in step (d) generally will be
25 more severe than the optional hydrolysis of the carrier before impregnation in pre-treatment step (i). Accordingly, this hydrolysis of the impregnated carrier is suitably carried out with steam at a temperature in the range of from 150 to 400 °C.

30 Preferably, the hydrolysed impregnated carrier is subsequently silylated in step (e). Silylation can be carried out by contacting the hydrolysed impregnated carrier with a silylating agent, preferably at a

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temperature of in the range of from 100 to 425 °C.
Suitable silylating agents include organosilanes such as
tetra-substituted silanes with C₁-C₃ hydrocarbyl
substituents. A very suitable silylating agent is
5 hexamethyldisilazane (HMDS).

Examples of suitable silylating methods and
silylating agents are, for instance, described in US
3829392 A and US 3923843 A which are referred to in US
6011162 A and in EP 734764 A.

10 The amount of titanium (as metallic titanium) will
normally be in the range of from 0.1 to 10 wt. %,
suitably in the range of from 1 to 5 wt. %, and most
preferably in the range of from 3 to 5 wt. %, based on
total weight of the catalyst. Preferably, titanium or a
15 titanium compound, such as a salt or an oxide, is the
only metal and/or metal compound present.

As mentioned above, it is well known in the art to
produce alkylene oxides, such as propylene oxide, by
epoxidation of the corresponding olefin using a
20 hydroperoxide such as hydrogen peroxide or an organic
hydroperoxide as the source of oxygen. The hydroperoxide
can be hydrogen peroxide or any organic hydroperoxide
such as tert-butyl hydroperoxide, cumene hydroperoxide
and ethylbenzene hydroperoxide.

25 The alkene will generally be propylene which gives
as alkylene oxide, propylene oxide.

Propylene for use in the epoxidation reaction may be
conveniently prepared by propane dehydrogenation or by
olefin metathesis as described in WO 2005/049534 A1 and
30 WO 2006/052688 A2. Such processes to prepare propylene
may be conveniently integrated with the process to
prepare propylene oxide. For example, WO 2011/118823 A1
describes an integrated process for preparing propylene

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oxide from propylene, wherein the propylene is first prepared in a propane dehydrogenation step. Processes for preparing propylene oxide which integrate epoxidation with propylene preparation via olefin metathesis reaction may also be conveniently employed.

The catalyst prepared according to the present invention has been found to give especially good results in epoxidation processes.

Therefore, the present invention further relates to a process for the preparation of alkylene oxide which process comprises contacting a hydroperoxide and alkene with a heterogeneous epoxidation catalyst and withdrawing a product stream comprising alkylene oxide and an alcohol and/or water, in which process the catalyst is prepared according to the present invention.

The hydroperoxide may be conveniently selected from hydrogen peroxide and organic hydroperoxides such as tert-butyl hydroperoxide, cumene hydroperoxide and ethylbenzene hydroperoxide.

A specific organic hydroperoxide is ethylbenzene hydroperoxide, in which case the alcohol obtained is 1-phenylethanol. The 1-phenylethanol usually is converted further by dehydration to obtain styrene.

Another method for producing propylene oxide is the co-production of propylene oxide and methyl tert-butyl ether (MTBE) starting from isobutane and propene. This process is well known in the art and involves similar reaction steps as the styrene/propylene oxide production process described in the previous paragraph. In the epoxidation step, tert-butyl hydroperoxide is reacted with propene forming propylene oxide and tert-butanol. Tert-butanol is subsequently etherified into MTBE.

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A further method comprises the manufacture of propylene oxide with the help of cumene. In this process, cumene is reacted with oxygen or air to form cumene hydroperoxide. Cumene hydroperoxide thus obtained is
5 reacted with propene in the presence of an epoxidation catalyst to yield propylene oxide and 2-phenyl propanol. The latter can be converted into cumene with the help of a heterogeneous catalyst and hydrogen. Specific suitable processes are described for example in WO 02/48126 A.

10 The conditions for the epoxidation reaction according to the present invention are those conventionally applied. For propene epoxidation reactions with the help of ethylbenzene hydroperoxide, typical reaction conditions include temperatures in the range of
15 from 50 to 140 °C, preferably in the range of from 75 to 125 °C, and pressures up to 80 bar with the reaction medium being in the liquid phase.

The invention is further illustrated by the following Examples.

20 Examples

Example 1

The silica gel carrier used in the examples had a surface area of 429 m²/g and a weight average particle size of about 1 mm. Substantially all particles had a
25 particle size between 0.6 and 2.0 mm.

75 gram samples of this silica gel carrier were dried at different temperatures for 2 hours.

Subsequently, the dried silica gel carriers thus obtained were contacted with a gas stream consisting of
30 titanium tetrachloride. The gas stream was obtained by heating titanium tetrachloride to 200 °C with the help of an electrical heating system. The silica carrier was impregnated with the titanium tetrachloride gas stream.

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The impregnated catalysts thus obtained were calcined at 600 °C for 7 hours. The calcined catalysts were subsequently contacted with steam at 325 °C for 6 hours. The steam flow consisted of 3 grams of water per hour and 8 Nl of nitrogen per hour. Finally, the catalysts were silylated at 185 °C for 2 hours by being contacted with 18 grams of hexamethyldisilazane per hour in a nitrogen flow of 1.4 Nl per hour.

The catalytic performance of the titanium catalyst samples was measured by testing the catalyst in a process for epoxidation of 1-octene.

In said 1-octene epoxidation test, 50 ml of a mixture containing 7.5 wt. % ethylbenzene hydroperoxide (EBHP) and 36 wt. % 1-octene in ethylbenzene (EB) was allowed to react with 1 g of epoxidation catalyst at 40 °C while being mixed thoroughly.

After 1 hour, the flask with the reaction mixture was cooled in ice/water to end the reaction and the reaction product was analysed by titration, spectroscopically or by gas chromatography (GC). Titration was carried out shortly after ending the test, as the reaction will still proceed at slower pace.

Table 1

Catalyst Sample	Drying temp. (°C)	Titanium content (wt. %)	Fines < 0.6 mm	Conversion (EBHP) (%)	Selectivity (OO/EBHP) (%)
A (Comp)	265	4.63	21.7	47.6	92.5
B	325	3.79	9.6	49.3	92.5
C	345	4.01	6.1	53.9	92.7
D	365	3.95	5.3	54.8	93.0
E	400	3.69	5.4	49.9	92.2
F	425	3.52	4.6	53.6	92.6

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As seen from Table 1, as the drying temperature increases the amount of fines (< 0.6 mm in size) formation is surprisingly reduced. This has a direct impact on the yield of the catalyst as the fines < 0.6 mm can lead to operational issues of abnormal pressure drops when catalyst is loaded in commercial reactors and therefore have to be discarded.

In addition, it is apparent from Table 1 that as the drying temperature increases, the titanium content (Ti load) on the catalyst also decreases, yet catalyst activity surprisingly increases. This indicates that the activity of the catalyst is not only governed by the Ti load but also on the way the titanium is incorporated onto the silica carrier.

Example 2

The afore-mentioned catalyst composition of Example 1 was prepared on a multi-ton scale and loaded in a commercial reactor set up for the epoxidation of propylene to propylene oxide.

Figures 1 and 2 compare the performance of this catalyst composition after carrier drying at 380 °C (Catalyst Sample G) with a sample of a titanium-containing catalyst typically used in the commercial epoxidation of propylene (Catalyst Sample H (comparative)).

The commercial reactors are operated in a so-called merry-go-round (MGR) fashion known in the art and as described, for example, in WO 2005/016903 A1.

For testing purposes, a mix for 35 wt. % ethylbenzene hydroperoxide (EBHP)/ethyl benzene (EB) was fed with propylene (C3=) to the reactor at a molar ratio of C3=:EBHP of 5:1.

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The fresh catalyst is loaded in the 4th MGR position and then it moved as it is ages from 4th to 1st MGR position, wherein it sees the fresh feed.

5 Figure 1 gives the plot of tonnes of PO made per Kg of catalyst used. As seen from the plot, Catalyst Sample G gives significantly more cumulative PO/kg of catalyst used in comparison to Catalyst Sample H. Also, it can be seen from Figure 1 that the deactivation rate (as seen by the slop of the decrease in the PO production with time)
10 is lower for Catalyst sample G.

Figure 2 gives the intrinsic activity of Catalyst Sample G and comparative Catalyst Sample H. It is apparent that the intrinsic activity of Catalyst Sample G is higher in comparison to comparative Catalyst Sample H.

15 In addition, it is also observed that the difference in activity between Catalyst Sample G vis-à-vis comparative Catalyst Sample H increases with time on-stream which is an indication that, surprisingly, Catalyst Sample H deactivates slowly in comparison to
20 catalyst sample G.

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C L A I M S

1. Process for the preparation of an epoxidation catalyst, which process comprises:
 - (a) drying a silica gel carrier having a surface area in the range of from 330 to 450 m²/g at a temperature in the
5 range of from 300 to 450 °C; and
 - (b) contacting the carrier obtained in step (a) with a gas stream containing titanium halide to obtain an impregnated carrier.
2. Process according to Claim 1, which process further
10 comprises:
 - (c) calcining the impregnated carrier obtained in step (b);
 - (d) hydrolysing the calcined impregnated carrier of step (c); and, optionally,
 - 15 (e) contacting the carrier obtained in step (d) with a silylating agent.
3. Process according to Claim 1 and/or 2, in which process the drying of step (a) is carried out at a temperature which is higher than the temperature at which
20 the impregnation of step (b) is carried out.
4. Process according to any of Claims 1 to 3, in which process the amount of titanium halide supplied in step (b) is such that the the molar ratio of titanium halide added to silicon present in the carrier is of from 0.050
25 to 0.063.
5. Process according to any of Claims 1 to 4, in which process the gas stream consists of titanium halide.
6. Process according to any of Claims 1 to 5, in which step (a) is performed in an oxygen-free atmosphere.

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7. Process according to any of Claims 1 to 6, wherein the silica gel carrier is dried for a period in the range of from 1 to 8 hours.
8. Catalyst prepared according to any of Claims 1 to 7.
- 5 9. Process for the preparation of alkylene oxide which process comprises contacting a hydroperoxide and alkene with an epoxidation catalyst and withdrawing a product stream comprising alkylene oxide and an alcohol and/or water, in which process the catalyst is prepared
- 10 according to the process of any of Claims 1 to 7.
10. Process according to Claim 9, wherein the alkene is propene and the alkylene oxide is propylene oxide.
11. Process according to Claim 9 or 10, wherein the hydroperoxide is ethylbenzene hydrogenperoxide and the
- 15 alcohol is 1-phenyl ethanol.
12. Process according to Claim 11, which process further comprises dehydration of 1-phenylethanol to obtain styrene.

Figure 1

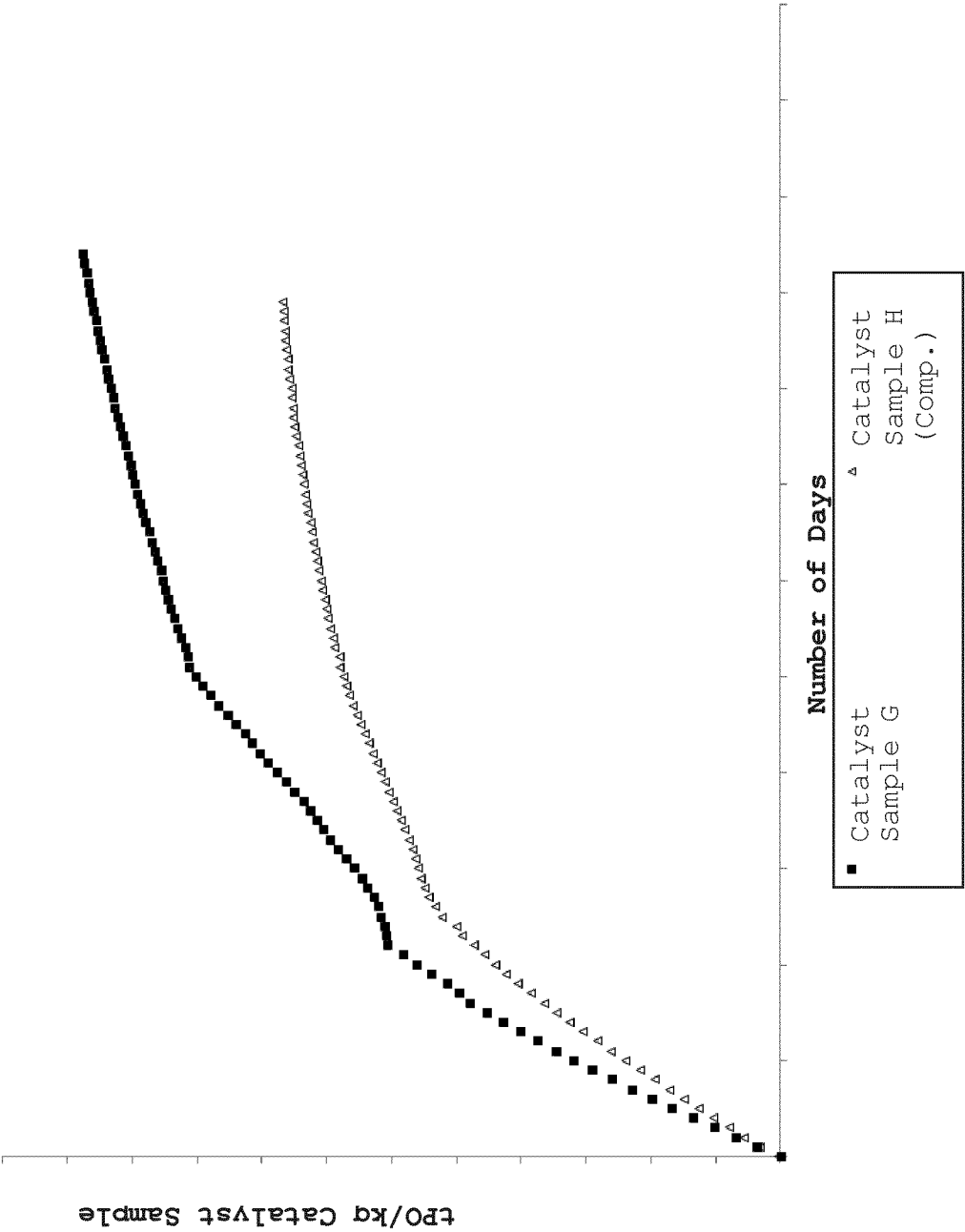
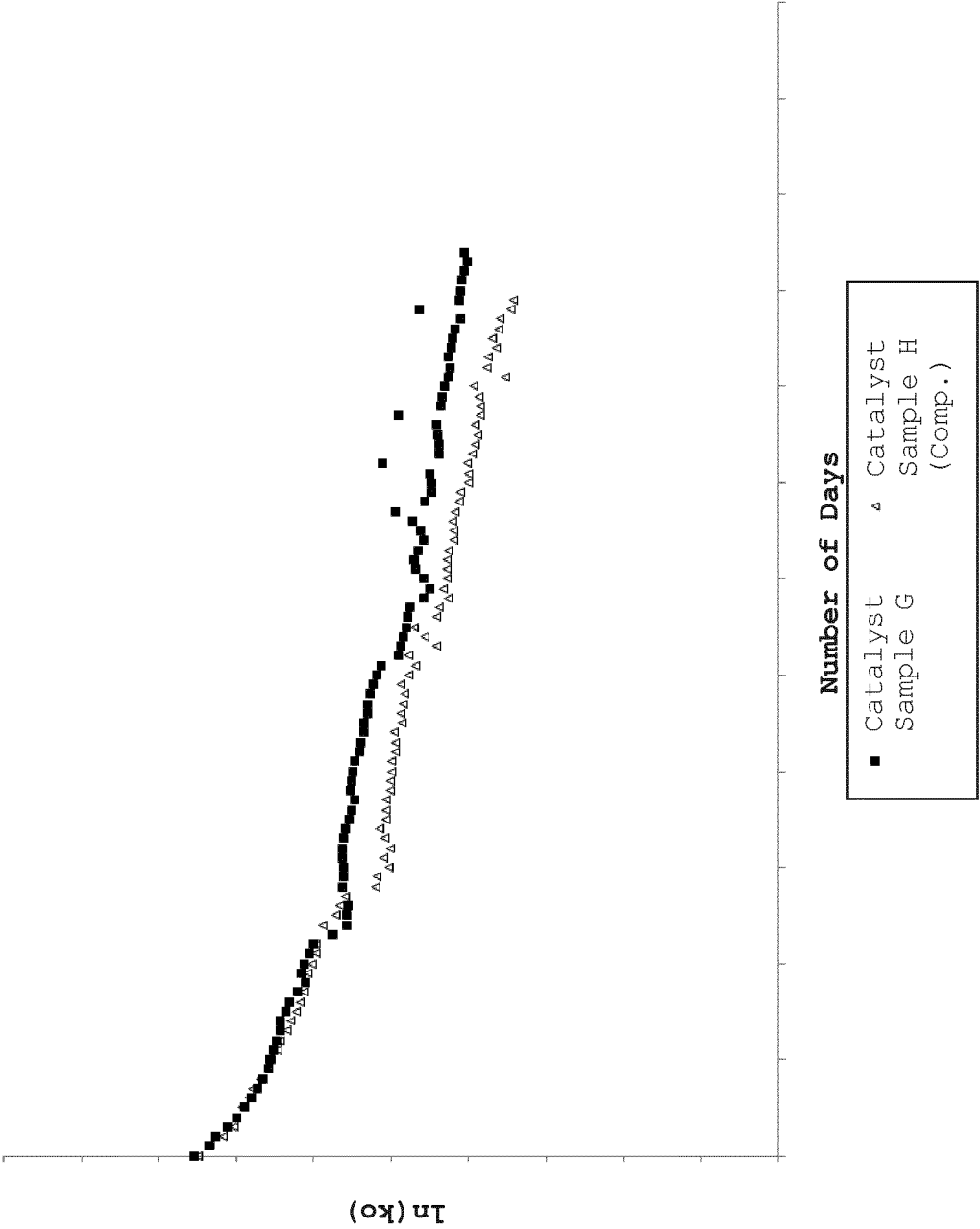


Figure 2



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/076872

A. CLASSIFICATION OF SUBJECT MATTER INV. C07D301/19 B01J21/08 B01J37/02 B01J35/10 B01J37/08 B01J21/06 ADD. 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) C07D B01J 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 practicable, search terms used) EPO-Internal, WPI Data								
C. DOCUMENTS CONSIDERED TO BE RELEVANT <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>X</td> <td> US 2007/260074 A1 (BUIJINK JAN KAREL FREDERIK [NL] ET AL) 8 November 2007 (2007-11-08) paragraph [0002] paragraph [0011] - paragraph [0014] paragraph [0018] paragraph [0023] - paragraph [0024] paragraph [0027] paragraph [0031] - paragraph [0032] paragraph [0035] - paragraph [0041] paragraph [0044] paragraph [0050] paragraph [0052] - paragraph [0054] examples B, 2, 3 table 1 claims 1-13 ----- </td> <td>1-12</td> </tr> </tbody> </table>			Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	X	US 2007/260074 A1 (BUIJINK JAN KAREL FREDERIK [NL] ET AL) 8 November 2007 (2007-11-08) paragraph [0002] paragraph [0011] - paragraph [0014] paragraph [0018] paragraph [0023] - paragraph [0024] paragraph [0027] paragraph [0031] - paragraph [0032] paragraph [0035] - paragraph [0041] paragraph [0044] paragraph [0050] paragraph [0052] - paragraph [0054] examples B, 2, 3 table 1 claims 1-13 -----	1-12
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X	US 2007/260074 A1 (BUIJINK JAN KAREL FREDERIK [NL] ET AL) 8 November 2007 (2007-11-08) paragraph [0002] paragraph [0011] - paragraph [0014] paragraph [0018] paragraph [0023] - paragraph [0024] paragraph [0027] paragraph [0031] - paragraph [0032] paragraph [0035] - paragraph [0041] paragraph [0044] paragraph [0050] paragraph [0052] - paragraph [0054] examples B, 2, 3 table 1 claims 1-13 -----	1-12						
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Date of the actual completion of the international search 3 January 2017		Date of mailing of the international search report 13/01/2017						
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Kyriopoulos, Aliko						

INTERNATIONAL SEARCH REPORT

Information on patent family members

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2007260074 A1	08-11-2007	AU 2007247223 A1	15-11-2007
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