The present invention relates to a process for preparing at least one compound chosen in the group consisting of 1, 4: 3, 6-dianhydro-D-mannitol, (3aS, 6S, 6aR) -6-hydroxytetrahydrofuro [3, 2-b] furan-3 (2H) -one, (3aS, 6R, 6aR) -6-hydroxytetrahydrofuro [3, 2-b] furan-3 (2H) -one and mixtures thereof, comprising a reaction of 1, 4: 3, 6-dianhydro-D-threo-2, 5-hexodiulose with hydrogen. The reaction can be advantageously carried out under mild conditions and gives high conversions and selectivities with low commercial production cost.
The present invention relates to a process for preparing at least one compound chosen in the group consisting of 1,4:3,6-dianhydro -D-mannitol, (3aS,6S,6aR)-6-hydroxytetrahydrofuro[3,2-b]furan-3(2H)-one, (3aS,6R,6aR)-6-hydroxytetrahydrofuro[3,2-b]furan-3(2H)-one and mixtures thereof, comprising a reaction of 1,4:3,6-dianhydro -D-threo-2,5-hexodiulose with hydrogen.

**PRIOR ART**

The following discussion of the prior art is provided to place the invention in an appropriate technical context and enable the advantages of it to be more fully understood. It should be appreciated, however, that any discussion of the prior art throughout the specification should not be considered as an express or implied admission that such prior art is widely known or forms part of common general knowledge in the field.

Isomannide (1,4:3,6-dianhydro -D-mannitol) is one of the isomers of isosorbide (1,4:3,6-dianhydro -D-sorbitol). It has been reported that this compound and its derivatives have been widely used in many areas such as building blocks for polymers synthesis, pharmaceutically important compounds, catalysts in asymmetric synthesis, chiral auxiliaries, and in the synthesis of ionic liquids.

There is a well-known process for the production of isomannide from mannitol by a dehydration reaction. WO8900162 A1 discloses a method for preparing isomannide using mannitol as starting material in the presence of formic acid and hydrogen fluoride. US2014088315A discloses a method for preparing anhydrosugar alcohols like isomannide using mannitol as starting material in the presence of low-priced acid catalyst. However, the industrial cost is quite high because mannitol is expensive due to its low availability.

Isomannide can be also obtained by isomerization of isosorbide but in low yield as disclosed by L. W. Wright, J. D. Brandner in J. Org. Chem. 1964, 29(10), 2979-2982. US20140371472 teaches a process for the preparation of isoidide from isosorbide. In this reaction, an aqueous solution of isosorbide is subjected to epimerization with
molecular hydrogen in the presence of a catalyst comprising ruthenium on a support. Isomannide only appears as a side-product at elevated temperatures.

Thus, there is still a need to produce isomannide or monoketones by a new method with low industrial cost, under mild reaction conditions affording high conversion and selectivity, and notably permitting to produce it from biomass-based feedstocks, such as isosorbide and its derivatives.

**INVENTION**

The present invention provides a process for preparing at least one compound chosen in the group consisting of 1,4;3,6-dianhydro \( \text{D} \)-mannitol (hereinafter referred to as isomannide), \( (3aS,6S,6aR) \)-6-hydroxytetrahydrofuro[3,2-b]furan-3(2H)-one (hereinafter referred to as monoketone), \( (3aS,6R,6aR) \)-6-hydroxytetrahydrofuro[3,2-b]furan-3(2H)-one (hereinafter referred to as monoketone) and mixtures thereof, comprising a reaction of 1,4;3,6-dianhydro \( \text{D} \)-threo-2,5-hexodiulose (hereinafter referred to as diketone) with hydrogen. The invented process not only overcomes the shortcomings of the above mentioned prior art references, but also enables high conversion and selectivity and low commercial production cost.

The invention also concerns a mixture comprising 1,4;3,6-dianhydro \( \text{D} \)-threo-2,5-hexodiulose and hydrogen.

Other characteristics, details and advantages of the invention will emerge even more fully upon reading the description which follows.

**DEFINITIONS**

For convenience, before further description of the present disclosure, certain terms employed in the specification, and examples are collected here. These definitions should be read in the light of the remainder of the disclosure and understood as by a person of skill in the art. The terms used herein have the meanings recognized and known to those of skill in the art, however, for convenience and completeness, particular terms and their meanings are set forth below.

The articles "a", "an" and "the" are used to refer to one or to more than one (i.e., to at least one) of the grammatical object of the article.
The term "and/or" includes the meanings "and", "or" and also all the other possible combinations of the elements connected to this term.

Throughout the description, including the claims, the term "comprising one" should be understood as being synonymous with the term "comprising at least one", unless otherwise specified, and "between" should be understood as being inclusive of the limits.

As used herein, metals of group IA (Li, Na, K, Rb, Cs, and Fr) are also known as alkali metals and metals of group IIA (Be, Mg, Ca, Sr, Ba, and Ra) are generally referred to as alkaline earth metals.

As used herein, metals of group IB, IIB, IIIB, IVB, VB, VIB, VIIB and VIIIB are often referred to as transition metals. This group comprises the elements with atomic number 21 to 30 (Sc to Zn), 39 to 48 (Y to Cd), 72 to 80 (Hf to Hg) and 104 to 112 (Rf to Cn).

As used herein, the lanthanides encompass the metals with atomic number 57 to 71 and the actinides the metals with the atomic number 89 to 103.

Ratios, concentrations, amounts, and other numerical data may be presented herein in a range format. It is to be understood that such range format is used merely for convenience and brevity and should be interpreted flexibly to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. For example, a temperature range of about 120°C to about 150°C should be interpreted to include not only the explicitly recited limits of about 120°C to about 150°C, but also to include sub-ranges, such as 125°C to 145°C, 130°C to 150°C, and so forth, as well as individual amounts, including fractional amounts, within the specified ranges, such as 122.2°C, 140.6°C, and 141.3°C, for example.

Should the disclosure of any patents, patent applications, and publications which are incorporated herein by reference conflict with the description of the present application to the extent that it may render a term unclear, the present description shall take precedence.
DETAILS OF THE INVENTION

Those skilled in the art will be aware that the present disclosure is subject to variations and modifications other than those specifically described. It is to be understood that the present disclosure includes all such variations and modifications. The disclosure also includes all such steps, features, compositions and compounds referred to or indicated in this specification, individually or collectively and any and all combinations of any or more of such steps or features.

Diketone of present invention could be obtained by any known methods. It can be notably a method producing diketone from isosorbide.

Diketone might be produced according to the method described in US2014039223, which comprises at least the steps of:

a) preparing a reaction mixture by adding at least one primary or secondary alcohol and a gas comprising oxygen and optionally also one or more solvents to a catalyst composition comprising a nitroxy radical-comprising compound, a NO source, and a carboxylic or mineral acid or an anhydride of a carboxylic or mineral acid,

b) incubating the reaction mixture at a temperature between 0 and 100°C or at a boiling point of the solvent, to obtain a reaction product,

c) crystallizing the reaction product during or after b), and

d) recovering the catalyst composition by removing the crystallized reaction product after c).

Diketone might also be produced according to the method described in US2011251399, which comprises the oxidation of primary or secondary alcohols with an oxygen-containing gas in the presence of a catalyst composition comprising at least one nitroxy radical, one or more NO sources and at least one or more carboxylic acids or anhydrides and/or mineral acids or anhydrides, optionally in the presence of one or more solvents, wherein the primary and secondary alcohols have a value of less than 2 for the decadic logarithm of the w-octanol-water partition coefficient (log P).

Monoketone of present invention refers to a compound obtained when only one carbonyl group of diketone is hydrogenated to hydroxyl group. Monoketone specifically refers to two isomers (3aS,6S,6aR)-6-hydroxytetrahydrofuro[3,2-b]furan-3(2H)-one and (3aS,6R,6aR)-6-hydroxytetrahydrofuro[3,2-b]furan-3(2H)-one.
(3aS,6S,6aR)-6-hydroxytetrahydrofuro[3,2-b]furan-3(2H)-one is the compound having formula as follows:

It should be understood by the people having ordinary skill in the art that diketone of present invention could be in the form of enols by tautomerization.

The enols above mentioned may be compound of formula (I) or compound of formula (II) as follows:

It should be understood by the people having ordinary skill in the art that diketone or its enols mentioned above could be used as reactant in present invention independently or in the form of mixtures.

Advantageously, the hydrogen in present invention may be molecular hydrogen, which is a colorless, odorless, tasteless, non-metallic highly flammable gas.
When hydrogen gas is used, the reaction may be carried out in the presence of air but preferably with an inert atmosphere such as N₂, Ar, CO₂. Those atmospheres may be introduced to the reaction mixture solely or in a form of mixture with H₂.

The hydrogen pressure of present invention may be comprised between 1 bar and 200 bars and preferably between 5 bars and 20 bars.

Hydrogen may also notably originate from a metal hydride. Said "Metal hydride" compounds comprise typically at least one metal atom (wherein the metal is as above defined) which is chemically bound to at least one hydrogen atom, wherein the electronegativity of the hydrogen atom is higher than the electronegativity of the metal atom.

Examples of metal hydride are alkali metal aluminum hydride, such as lithium aluminum hydride (LiAlH₄) and alkali metal borohydride, such as sodium borohydride (NaBH₄).

The molar ratio of metal hydride to diketone of present invention might be comprised from 1:1 to 20:1 and preferably from 1:1 to 10:1 and more preferably from 3:1 to 6:1.

In one embodiment, the hydrogenation reaction of present invention could be performed in the absence of a catalyst when specific reactant, such as metal hydride is used.

In another embodiment, when hydrogenation catalyst is optionally employed, it is not particularly limited and might be any substance having catalyst activity in converting diketone to at least one compound chosen in the group consisting of isomannide, monoketones and mixtures thereof. It could be homogeneous catalyst or heterogeneous catalyst.

The hydrogenation catalyst of present invention may comprise at least one metal element in elemental form and/or at least one metal compound of at least one metal element, wherein the metal element is chosen in the group consisting of: (i) elements of group IA, IIA, IIIA, IVA, VA, VIA and VIIA of the Periodic Table, (11) elements of groups IB, IIB, IIIB, IVB, VB, VIB, VIIB and VIIIB of the Periodic Table, (111) lanthanides, (iv) actinides, and (v) any combination thereof.
In present invention, hydrogen is not included in metal element chosen in Group IA of the Periodic Table. Carbon is not included in metal element chosen in Group IVA of the Periodic Table. Nitrogen and phosphorus are not included in metal element chosen in Group VA of the Periodic Table. Oxygen, sulfur and selenium are not included in metal element chosen in Group VIA of the Periodic Table.

Some of the elements encompassed by the description above and understood to be metals for the purpose of the present invention, are sometimes also referred to as metalloids. The term metalloid is generally designating an element which has properties between those of metals and non-metals. Typically, metalloids have a metallic appearance but are relatively brittle and have a moderate electrical conductivity. The six commonly recognized metalloids are boron, silicon, germanium, arsenic, antimony, and tellurium. Other elements also recognized as metalloids include aluminum, polonium, and astatine. On a standard periodic table all of these elements may be found in a diagonal region of the p-block, extending from boron at one end, to astatine at the other.

In one embodiment, the hydrogenation catalyst of present invention comprises one and only one metal element in elemental form.

The only one metal element in elemental form may be notably chosen in the group consisting of elements of groups IB, IIB and VIIIB of the Periodic Table. Preferably, the only one metal element in elemental form may be chosen in the group consisting of Pt, Pd, Rh, Ru, Au, Ag, Ni, Co, Fe, Zn and Cu.

In another embodiment, the hydrogenation catalysts of present invention comprise a mixture comprising at least two metal elements in elemental form.

In still another embodiment, the hydrogenation catalysts of present invention comprise a metal alloy comprising at least two metal elements in elemental form.

A metal alloy can be viewed as a solid metal-solid metal mixture wherein a primary metal acts as solvent while other metal(s) act(s) as solute; in a metal alloy and wherein the concentration of the metal solute does not exceed the limit of solubility of the metal solvent.
Preferably, the two metal elements of mixture comprising at least two metal elements in elemental form or metal alloy comprising at least two metal elements in elemental form are chosen in the group consisting of elements of groups IIIA, IVA, VA, VIA, IB, IIB, IIIB, IVB, VB, VIB, VIIB and VIIIB of the Periodic Table.

More preferably, the two metal elements of mixture comprising at least two metal elements in elemental form or metal alloy comprising at least two metal elements in elemental form are chosen in the group consisting of elements of groups IB, IIB, IIIB, IVB, VB, VIB, VIIB and VIIIB of the Periodic Table and metalloids.

In a preferred embodiment, the two metal elements of mixture comprising at least two metal elements in elemental form or metal alloy comprising at least two metal elements in elemental form are chosen in the group consisting of Pt, Pd, Rh, Ru, Au, Ag, Ni, Co, Fe, Zn, Cu, Sn, B, Al, Si, Sb, Bi and Ge.

The metal alloy may be notably selected from the group consisting of Pt-Au, Pt-Pd, Pt-Sn, Pt-Bi, Pt-Fe, Rh-Ag, Rh-Au and Raney nickel alloys. Raney nickel alloys are preferable among these alloys.

Raney nickel is an alloy containing catalytically active nickel and a catalytically inactive component, such as aluminum or silicon. The Raney nickel alloy always has a very high surface area and also contains hydrogen gas (H₂) adsorbed on the nickel surface.

In present invention, the components and their corresponding contents of Raney nickel is not particularly limited. All Raney nickel could be selected as hydrogenation catalyst if it has catalytic activity for converting diketone to at least one compound chosen in the group consisting of isomannide, monoketones and mixtures thereof.

The Raney nickel mentioned above may notably be Ni-Al, Ni-Si, Ni-Sn, Ni-Co-Si alloys. Among these, Ni-Al alloy is more preferable.

The process according to the invention notably relates to the hydrogenation reaction converting diketone to at least one compound chosen in the group consisting of isomannide, monoketones and mixtures thereof in the presence of a Ni-Al Raney nickel alloy.
In one embodiment of the invention, the catalyst may have a total aluminum content of at most 10% by weight with respect to the total weight of Ni-Al Raney nickel alloy.

In a preferred embodiment of the invention, the total aluminum content may be greater than or equal to 1% by weight with respect to the total weight of Ni-Al Raney nickel alloy.

Preferably, the total aluminum content may be comprised from 1% to 10% by weight with respect to the total weight of Ni-Al Raney nickel alloy. Even more advantageously, the total aluminum content may be comprised from 2% to 8% by weight with respect to the total weight of Ni-Al Raney nickel alloy.

The metal alloy, especially Raney nickel may further comprise at least one dopant. Among the conventional dopants in this field, exemplary are elements of groups IVB, VB, VIB, VIIB and VIIIB of the Periodic Table. Preferably, the dopant may notably be chosen from the group consisting of Zn, Fe, Ti, Mo, V, Cr, Co, Mn and combinations thereof.

In present invention, the catalyst may comprise at least one metal compound of at least one metal element.

The metal compound of present invention may notably be metal complex. "Metal complex" is a substance consists of a central atom or ion, which is usually metallic and is called the coordination center, and a surrounding array of bound molecules or ions, that are in turn known as ligands or complexing agents.

The metal complex is not particularly limited. It should be understood by the people having ordinary skill in the art may use any metal complex as a hydrogenation catalyst mentioned in prior arts, such as ruthenium-based transition metal complexes catalyst as described in US2015057450.

The hydrogenation catalyst of present invention could be prepared on a support. The support is not particularly limited. For example, the support might be chosen in the group consisting of silica, alumina, ceria, titania, zirconia, carbon and graphite powder.

Still for example, the support might be some inorganic salts, such as alkali metal or
alkaline earth metal carbonate, alkali metal or alkaline earth metal sulfate. Among these, water-insoluble salts, such as calcium carbonate or barium sulfate are preferred. The loading amount of catalyst on support may be comprised from 0.01 % to 20 % by weight with respect to the total weight of supported catalyst. Preferably, the loading amount of catalyst on support may be comprised from 1 % to 15 % by weight.

Examples of supported catalyst are Pd/C, Pt/C, Rh/C, Ru/C, Au/C, Pd-Bi/C, Pd/CeO₂, Pd/AlO₃, Pt/Al₂O₃, Rh/Al₂O₃, Ru/Al₂O₃, Au/Al₂O₃ and Pd-Bi/Al₂O₃. Preferably, the hydrogenation reaction temperature may be comprised from -100°C to +300°C. Preferably, the reaction temperature is comprised from -50°C to +250°C and more preferably from 0°C to +150°C.

In one embodiment, the hydrogenation reaction temperature may be comprised from 0°C to +150°C when Raney nickel is employed in the reaction.

The hydrogenation reaction time of present invention may be comprised from 0.5 hour to 30 hours. Preferably, the reaction time may be comprised from 1 hour to 20 hours and more preferably from 5 hours to 15 hours.

In one embodiment, diketone could be introduced into the reaction in the absence of a solvent. For example, solvent might not be used when the reaction temperature is equal to or higher than the melting point of diketone.

In another embodiment, diketone could be dissolved in a solvent before being introducing into a reaction. The concentration of diketone is not particularly limited and may be preferably comprised from 10 % to 90 % by weight. More preferably, the diketone concentration may be comprised from 15 % to 30 % by weight.

The solvents are not particularly limited. Any solvent has good solubility for diketone could be used in present invention. The solvent might be chosen in the group consisting of water, alkane, alkene, arene, halogenated-hydrocarbon, ether, ester, ketone, alcohol, or any combination thereof. Exemplary solvents include methanol, ethanol, isopropanol, acetone, tetrahydrofuran, and any combination thereof.

The amount of hydrogenation catalyst employed, expressed by the ratio of the weight
of metal comprised in catalyst to the weight of diketone, can vary, for example, from 0.0001:1 to 2:1.

In one embodiment, when Raney nickel is employed as catalyst, the ratio of the weight of metal comprised in catalyst to the weight of diketone might be comprised from 0.01:1 to 1:1 and preferably from 0.2:1 to 0.5:1.

In another embodiment, when noble metal, such as Pt, Pd, Rh, Ru, Au and Ag is employed as catalyst, the ratio of the weight of metal comprised in catalyst to the weight of diketone might be comprised from 0.0001:1 to 0.3:1, preferably from 0.0005:1 to 0.15:1, and more preferably still from 0.005:1 to 0.1:1.

The invented process may be carried out either in batch, semi-batch or in continuous mode. Furthermore, the process is not linked to a particular reactor type.

The following examples are included to illustrate embodiments of the invention. Needless to say, the invention is not limited to the described examples.

**EXPERIMENTAL PART**

**EXAMPLE 1**

In a 30-mL autoclave equipped with a magnetic stirrer and an aluminum heating block, diketone (0.5 g, 3.5 mmol) is dissolved in ethanol (96 %) (2 ml) and 60 mg of catalyst, related to the mass of dry solid is added. Two catalysts are screened here: Raney®-Nickel slurry in P40, active catalyst, from W.R. Grace and Co., reference 2800, and aluminum-nickel alloy purum, 50 % Al basis, 50 % Ni basis (Sigma-Aldrich). The autoclave is then pressurized with hydrogen (10 bars), heated at given temperature and vigorously stir with magnetic bar (600 rpm) for 2h, unless otherwise specified. After the reaction, the mixture is diluted in methanol (1 ml) and 1-decanol is added as internal standard for GC analysis. Results can be found in Table 1.
Table 1

<table>
<thead>
<tr>
<th>Catalyst</th>
<th>Temperature</th>
<th>Conversion (%)</th>
<th>Isomannide yield (%)</th>
<th>Monoketone + isosorbide yield (%)</th>
<th>Isoidide yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 %Al-50%Ni alloy</td>
<td>25°C</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>50 %Al-50%Ni alloy</td>
<td>100°C</td>
<td>97</td>
<td>18.2</td>
<td>6.5</td>
<td>0</td>
</tr>
<tr>
<td>Raney®2800</td>
<td>25°C</td>
<td>99</td>
<td>41.7</td>
<td>25.2</td>
<td>0</td>
</tr>
<tr>
<td>Raney®2800</td>
<td>100°C</td>
<td>99</td>
<td>36.5</td>
<td>12.5</td>
<td>0</td>
</tr>
<tr>
<td>Raney®2800*</td>
<td>25°C</td>
<td>99</td>
<td>46.8</td>
<td>10.0</td>
<td>0</td>
</tr>
</tbody>
</table>

Yields are expressed in molar percentage. * 16h instead of 2h

EXAMPLE 2

5 This experiment was performed using the same equipment as EXAMPLE 1 using the following conditions: diketone (0.5 g, 3.5 mmol), catalyst (20 mg based on the metal on support for Ru/C (Johnson Matthey Type D101002-5, 58.46% in water), 1 wt. % of metal compare to diketone), ethanol (2 mL) as solvent, ¾ (10 bars), for 16h at given temperature.

10 After the reaction, the mixture was diluted in methanol (1 mL) and 1-decanol was added as internal standard for GC analysis. Results can be found in Table 2.

Table 2

<table>
<thead>
<tr>
<th>Catalyst</th>
<th>Temperature</th>
<th>Conversion (%)</th>
<th>Isomannide yield (%)</th>
<th>Monoketone + isosorbide yield (%)</th>
<th>Isoidide yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ru/C (5 wt. %)</td>
<td>25°C</td>
<td>22.7</td>
<td>5.3</td>
<td>17.4</td>
<td>0</td>
</tr>
<tr>
<td>Ru/C (5 wt. %)</td>
<td>100°C</td>
<td>&gt;97</td>
<td>73.7</td>
<td>17.8</td>
<td>0</td>
</tr>
</tbody>
</table>

EXAMPLE 3

15 This experiment was performed using the same protocol as EXAMPLE 1 using the following conditions: diketone (0.5 g, 3.5 mmol), catalyst (20 mg based on the metal on support for Pd/C (Johnson Matthey Type 39 paste, 54.9% in water), 1 wt. % of metal compare to diketone), ethanol (2 mL) as solvent, H₂ (10 bars), for 16h at 25°C. 18.4% of isomannide was obtained with a conversion of 67.7% of the diketone and 39.3% of monoketone isomers.
EXAMPLE 4
This experiment was performed using the same protocol as EXAMPLE 3 using the Pt-Bi/C catalyst provided by Johnson Matthey, Type 5R160 paste, 57.4% in water at given temperature. Results can be found in Table 3.

<table>
<thead>
<tr>
<th>Catalyst</th>
<th>Temperature</th>
<th>Conversion (%)</th>
<th>Isomannide yield (%)</th>
<th>Monoketone + isosorbide yield (%)</th>
<th>Iosidide yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 wt. % Pt-1</td>
<td>25°C</td>
<td>79.9</td>
<td>47.2</td>
<td>32.7</td>
<td>0</td>
</tr>
<tr>
<td>wt. % Bi/C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 wt. % Pt-1</td>
<td>100°C</td>
<td>&gt;97</td>
<td>59.8</td>
<td>8.4</td>
<td>0</td>
</tr>
<tr>
<td>wt. % Bi/C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

EXAMPLE 5
In a 25mL 2-necked balloon equipped with a magnetic stirrer, water condenser and a dropping funnel, a solution of diketone (0.25 g, 1.75 mmol in mL water) is prepared. A solution of NaBH₄ (7.9mmol, 0.3 g in mL water) is added dropwise over 2h. After the reaction, the solvent is removed under vacuum and the remaining white solid is analyzed using ¹H NMR. A 90% yield of isomannide is obtained.
CLAIMS

1. A process for preparing at least one compound chosen in the group consisting of 1,4:3,6-dianhydro-D-mannitol, (3aS,6S,6aR)-6-hydroxytetrahydrofuro[3,2-b]furan-3(2H)-one, (3aS,6R,6aR)-6-hydroxytetrahydrofuro[3,2-b]furan-3(2H)-one and mixtures thereof, comprising a reaction of 1,4:3,6-dianhydro-D-threo-2,5-hexodiulose with hydrogen.

2. The process according to claim 1, wherein the reaction is performed in the presence of a hydrogenation catalyst, which comprises at least one metal element in elemental form and/or at least one metal compound of at least one metal element, wherein the metal element is chosen in the group consisting of: (i) elements of groups IA, IIA, IIIA, IVA, VA, VIA and VIIA of the Periodic Table, (ii) elements of groups IB, IIB, IIIB, IVB, VB, VIB, VIIB and VIIIB of the Periodic Table, (iii) lanthanides, (iv) actinides, and (v) any combination thereof.

3. The process according to claim 2, wherein hydrogenation catalyst comprises only one metal element in elemental form chosen in the group consisting of elements of groups IB, IIB and VIIIB of the Periodic Table.

4. The process according to claim 2 or 3, wherein hydrogenation catalyst comprises only one metal element in elemental form chosen in the group consisting of Pt, Pd, Rh, Ru, Au, Ag, Ni, Co, Fe, Zn and Cu.

5. The process according to claim 2, wherein hydrogenation catalyst comprises a mixture comprising at least two metal elements in elemental form.

6. The process according to claim 2, wherein hydrogenation catalyst comprises a metal alloy comprising at least two metal elements in elemental form.

7. The process according to claim 6, wherein hydrogenation catalyst comprises a metal alloy chosen in the group consisting of Pt-Au, Pt-Pd, Pt-Sn, Pt-Bi, Pt-Fe, Rh-Ag, Rh-Au and Raney nickel alloys.

8. The process according to claim 7, wherein hydrogenation catalyst comprises Ni-Al Raney nickel alloy.
9. The process according to claim 8, wherein the total aluminum content is comprised from 1 % to 10 % by weight with respect to the total weight of Ni-Al Raney nickel alloy.

10. The process according to claim 8 or 9, wherein the metal alloy further comprises a dopant chosen from the group consisting of elements of groups IVB, VB, VIB, VIIB and VIIIB of the Periodic Table.

11. The process according to any one of claims 8 to 10, wherein the ratio of the weight of metal comprised in catalyst to the weight of diketone is comprised from 0.2: 1 to 0.5:1.

12. The process according to claim 2, wherein hydrogenation catalyst comprises a metal complex.

13. The process according to any one of claims 1 to 12, wherein the hydrogen originates from a metal hydride and the molar ratio of metal hydride to 1,4;3,6-dianhydro-D-threo-2,5-hexodiulose is comprised from 1:1 to 20:1.

14. The process according to any one of claims 1 to 13, wherein the concentration of diketone in the solvent is comprised from 15 % to 30 % by weight.

15. At least one compound chosen in the group consisting of 1,4;3,6-dianhydro-D-mannitol, (3aS,6S,6aR)-6-hydroxytetrahydrofuro[3,2-b]furan-3(2H)-one, (3aS,6R,6aR)-6-hydroxytetrahydrofuro[3,2-b]furan-3(2H)-one and mixtures thereof obtainable by a reaction of 1,4;3,6-dianhydro-D-threo-2,5-hexodiulose with hydrogen.

16. Mixture comprising 1,4;3,6-dianhydro-D-threo-2,5-hexodiulose and hydrogen.
INTERNATIONAL SEARCH REPORT

PCT/CN2016/111217

A. CLASSIFICATION OF SUBJECT MATTER
C07D 493/04(2006.01)

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 493/-

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)
CNKI, CNABS, VEN, STN (REG,CAP) isomannide, isosorbide, hexodiulose, hydrogen, cataly?, RN: 641-74-7, RN: 13241-36-6

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<td>A</td>
<td>CN 104169288 A (STICHTING DIENST LANDBOUWKUNDI) 26 November 2014 (2014-11-26) claims 1-13</td>
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<td>US 4543168 A (ROQUETTE FRERES) 24 September 1985 (1985-09-24) claims 1-12</td>
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<td>A</td>
<td>FR 1426204 A (ATLAS CHEM IND) 28 January 1966 (1966-01-28) claims 1-4</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

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Date of the actual completion of the international search 11 March 2017 | Date of mailing of the international search report 24 March 2017

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## INTERNATIONAL SEARCH REPORT

Information on patent family members

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<td>IN 7472DEN2014 A</td>
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<td></td>
<td>EP 2817314 A1</td>
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<td>CN 104169288 B</td>
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<td></td>
<td>WO 2013125950 A1</td>
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</tr>
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<td></td>
<td>JP 2015508773 A</td>
<td>23 March 2015</td>
</tr>
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<td></td>
<td>FR 2545006 A1</td>
<td>09 November 1984</td>
</tr>
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<td></td>
<td>EP 0125986 A1</td>
<td>21 November 1984</td>
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