

dioxanones. In a specific aspect, the invention relates to a process for preparing 2-para-dioxanones by the catalytic dehydrogenation of dialkylene glycols, and to the dehydrogenation catalyst used.

2-Para-dioxanones are used as a starting material in the manufacture of poly(2-para-dioxanones). The poly 2-para-dioxanones are used in the manufacture of adsorbable monofilament suture fibres and other adsorbable medical devices.

One method of preparing 2-para-dioxanones is by oxidative dehydrogenation of dialkylene glycols. In U.S. Patent Nos. 2,900,395 and 2,807,629, a copper chromite catalyst is used for the oxidative dehydrogenation of diethylene glycol. However, these patents report a yield of about 67-84% and a conversion of about 67-94%.

It has been found that the presence of impurities inhibit polymerization. Typical impurities in the preparation of 2-para-dioxanone include, unreacted dialkylene glycol and reaction by-products such as 2-para-dioxanol, para-dioxane, 2,3-dihydro-para-dioxin (dioxene), alkylene glycol and carboxylic acids. Particularly, the production of carboxylic acids and hydroxylic compounds can hinder polymerization of 2-para-dioxanones. Therefore, a process to produce a high purity 2-para-dioxanone ("polymerization grade") is desirable.

It is therefore an object of the present invention to provide a 2-para-dioxanone preparation process with high conversion rate and selectivity.

According to the invention, a process for the production of 2-para-dioxanones is provided which comprises:

contacting a dialkylene glycol at a temperature within the range of 200°C to 400°C with an effective amount of a

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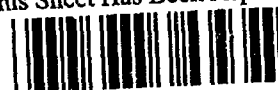
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It has been found that 2-para-dioxanones can be produced in high yields with minimal side-reactions by contacting a dialkylene glycol with an effective amount of a dehydrogenation catalyst. Further, it has been found that by preferably impregnating the alumina with a promoter prior to metal mixture impregnation, a dehydrogenation catalyst which has conversion as high as about 100% and/or selectivity as high as about 98% can be obtained.

Suitable promoters can be compounds (including, salts, compounds and complexes) of alkali metals and alkaline earth metals. The promoters must be soluble in a suitable solubilizing media, either organic or inorganic. Water is a preferred solubilizing media. Lower alkanols and ethers also provide examples of suitable organic solvents. Preferred promoters include, for example, compounds of sodium, potassium, lithium, calcium, magnesium and mixtures thereof. The promoter is typically present in an amount sufficient to suppress para-dioxane formation. The promoter is preferably present in an amount of from 0.1 to 20 weight percent, more preferably from 0.5 to 10 weight percent measured as the metal per total weight of the dehydrogenation catalyst. The optimum catalyst contains 1 to 5 weight percent of promoter measured as the metal per total weight of the catalyst.

The carrier utilized in the catalyst of the invention is an alumina. A porous alumina, more preferably a gamma-alumina, having a B.E.T. surface area greater than $100 \text{ m}^2/\text{g}$ is preferred. An alumina with a lower surface area than $100 \text{ m}^2/\text{g}$ is also acceptable, however, activity decreases with decreasing surface area while maintaining the selectivity level of the dehydrogenation catalyst. The B.E.T. method for determining specific surface area is described in detail in Brunauer, S., Emmet, P. H., and Teller, E.J., J. Am. Chem. Soc., 60, 309-16 (1938). The most suitable

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silica increases the presence of impurities in the reaction product and should be avoided. Suitable commercial aluminas include, Vista Catapal Series; AX-200 type from Criterion Catalyst Co., L.P.; and A-201 from La Roche Aluminas.

10 The dehydrogenation catalyst can be prepared by impregnating the alumina support with solubilized compounds (including, salts, compounds and complexes) of copper, zinc, a promoter, and optionally chromium. The impregnation can be carried out in any order or simultaneously. In a preferred embodiment, the promoter is first impregnated on the alumina support, then dried and
15 optionally calcined. The dried (and calcined) material is then impregnated with a solution having copper, zinc and optionally chromium compounds dissolved therein. The alumina can be impregnated in a one-step process by using a single solution copper, zinc and optionally chromium compounds or in a multi-step
20 process, using one or more of copper, zinc and optionally chromium compounds dissolved in individual impregnating solutions. It is preferred to use just a sufficient amount of impregnating solution containing all the requisite metal compounds such that all the pore volume in the support is filled and no excess solution is left
25 after impregnation.

The alkali and alkaline earth promoters can be impregnated on alumina in the form of compounds (including, salts, compounds and complexes) such as, for example, hydroxides, chlorides, bromides, nitrates, acetates, lactates, carbonates, bicarbonates, oxides,
30 oxalates, sulfates and the like. Carbonates and bicarbonates are preferred because of ease of use. Suitable copper, zinc and chromium compounds includes, for example, chlorides, bromides, nitrates, acetates, lactates, carbonates, bicarbonates, oxides, oxalates, sulfates and the like. Nitrates are preferred for ease
35 of decomposition.

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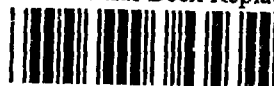


carried out at a temperature within the range of from 100°C to 900°C, preferably from 300°C to 800°C. The drying and calcining steps can be carried out in one continuous step, heating the material slowly through the low temperature ranges to dry the material and then raising the temperature to the calcining conditions. The drying step is preferably carried out in the initial stages of the calcination step if the alumina is calcined. The impregnated material is calcined to convert the soluble metal compounds to oxides or oxygen-containing compounds upon the alumina support. Calcining is carried out in a neutral or oxidizing atmosphere, air being the preferred atmosphere. Nitrogen is also a suitable alternative atmosphere. The times for the drying and calcining steps are not critical and are dependent upon the temperatures utilized. The drying and calcining times are typically in the range of from 5 minutes to 24 hours, although longer times are acceptable.

The calcined material is then activated by subjecting the catalyst to a reducing condition prior to use. The reducing condition may be either a gaseous atmosphere or a suitable liquid solution.

Suitable examples of a gaseous reducing atmosphere comprise hydrogen, ammonia, carbon monoxide, mixtures thereof and the like. The gaseous reducing atmosphere may also optionally contain inert gases such as nitrogen. The preferred atmosphere is hydrogen. Activation temperatures when utilizing a gaseous atmosphere range from 175°C to 550°C. The time needed for activation in a gaseous atmosphere will depend on the temperature, the higher the temperature, the shorter the time and the lower the temperature, the longer the activation. Typically, useful times have been found to range from 0.01 hour to 24 hours. Although times outside these limits are also useful, economic considerations generally dictate

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increase the lifetime of the catalyst.

Liquid solutions suitable for providing reducing conditions include, for example, aqueous or ammoniacal solutions of hydrazine, sodium borohydride or formaldehyde or solutions of triethyl aluminium or di-isobutyl aluminium hydride in an organic solvent such as heptane. The catalysts can be activated using reducing liquid solutions within a range of from 25°C or higher, preferably from 25°C to 100°C, for a time of from 0.01 hours to 10 hours or longer. Temperatures and time are not critical and are dependent upon the reducing solution being utilized.

While not wishing to be bound by any particular theory, it is believed that the activation of the catalyst under reducing conditions at least partially reduces the copper from the +2 valence state to the +1 and/or 0 valence state, which is believed to contribute to the catalytic activity of the catalyst. Reducing conditions, however, preferably should not be so severe as to reduce the zinc oxides and chromium oxides. Preferably, the promoters are present on the catalyst in the oxidized form, even after subjecting to reducing conditions. They are believed to be present in the form of oxides or oxygen-containing compounds and may be combined with the alumina support and/or other catalyst components.

The appropriate activation conditions can readily be determined by experimentation. For example, times and temperatures can be varied and the resultant catalytic material can be examined by x-ray photoelectron spectroscopy in order to determine the activation state of the copper. Alternatively, the catalyst's catalytic activity can be determined and utilized to determine optimum activating conditions.

The amount of metals deposited upon the support are not critical and may be varied through a wide range so long as they are

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is present in a mole ratio of zinc to copper or from 0.01:1 to 5:1, more preferably from 0.01:1 to 1.5:1. Chromium can optionally be present in an amount of 0 to 25 weight percent measured as metal per total weight of the dehydrogenation catalyst.

10 The dialkylene glycol corresponding to the desired optionally alkyl-substituted 2-para-dioxanone is contacted, in a reaction zone, with an effective amount of a dehydrogenation catalyst (prepared as described above) to produce the 2-para-dioxanone at a temperature within the range of from 200°C to 400°C, preferably from 250°C to 300°C. A temperature of less than 300°C is
15 preferred for longer catalyst life. The reaction is carried out at a pressure within the range of 10 to 2000 kPa (0.1 to 20 atmosphere), preferably from 50 to 500 kPa (0.5 to 5 atmosphere).

20 In a particularly preferred embodiment, the dehydrogenation catalyst preferably does not contain chromium for environmental disposal reasons. For longer catalyst life-time, dehydrogenation catalysts having a relatively higher copper loading, for instance, alumina having copper in the amount of at least 4 weight percent measured as metal per total weight of the dehydrogenation catalyst
25 is preferred. Promoter is preferably present in an amount of less than 15 weight percent measured as metal per total weight of the dehydrogenation catalyst to minimize side-reactions.

The inventive process can be carried out in vapour phase, liquid phase or can be refluxed in the presence of the dehydrogen-
30 ation catalyst. The reaction is preferably carried out neat, but can be in an inert solvent or environment. The process can further be carried out in a batch process or in a continuous process.

In a continuous process, the liquid hourly space velocity (LHSV) at the reaction zone is at a rate effective to form
35 2-para-dioxanones, preferably within the range of from 0.1 to

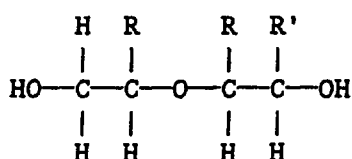
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5 be suitable. Currently, the reaction is more preferably carried
out in an inert gas/hydrogen atmosphere containing hydrogen to
inert gas ratio from 1:0.01 to 1:50. In a particularly preferred
embodiment, the process is carried out continuously at a
10 temperature in the range of from 260°C to 290°C, a pressure in the
range of from 50 to 200 kPa (0.5 to 2 atmosphere) and a LHSV within
the range of from about 0.5 to 2 h⁻¹. The process can be carried
out in fluidized beds or packed columns, with packed columns being
preferred due to ease of operation.

15 In a batch process, the catalyst is present in an amount
effective to form 2-para-dioxanones, preferably in an amount of
from 0.1 weight percent to 50 weight percent, more preferably from
1 weight percent to 20 weight percent based on the weight of the
dialkylene glycol.

Suitable dialkylene glycol can be represented by the formula



20 in which each R and R' are independently hydrogen or C₁₋₂₀ alkyl.
Preferably R' is hydrogen. Preferably R is independently hydrogen
or C₁₋₁₂, most preferably hydrogen or C₁₋₂. Examples of the most
preferable dialkylene glycols include, diethylene glycol,
dipropylene glycol and dibutylene glycol. The inventive process
25 is especially suitable for production of 2-para-dioxanone by the
dehydrogenation of diethylene glycol.

The dehydrogenation catalyst can be regenerated after use or
during use to extend the catalyst life and/or to obtain higher
overall conversion and selectivity. The regeneration can be
30 performed at any convenient time as necessary. For example, the
spent catalyst can be regenerated in situ or removed from the
reactor and regenerated separately.

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also suitable atmosphere. For example, in a continuous process, the catalyst can be regenerated in situ by first stopping the flow of the feed over the catalyst and cooling the catalyst to about room temperature. Then the catalyst can be regenerated by contacting the catalyst in a neutral or oxidizing atmosphere at an elevated temperature with a flow of the atmosphere. After the catalyst is regenerated, the catalyst is reactivated prior to use.

The inventive process allows formation of highly pure 2-para-dioxanone with minimal side-reactions. Impurities such as carboxylic acids, hydroxylic compounds and dioxane are minimized while obtaining high conversion and selectivity.

The following illustrative embodiments describe the process of the invention and are provided for illustrative purposes and are not meant as limiting the invention.

EXAMPLE 1

This example demonstrates preparation of a dehydrogenation catalyst according to the inventive process.

A solution of 2.04g (13.3 mmol) K_2CO_3 in 30 mL of distilled water was added slowly to 50.20g of neutral γ -Alumina with a surface area of $120\text{ m}^2/\text{g}$ (AX-200 from Criterion Catalyst Co., L.P.). The impregnated catalyst was then dried at 100°C . After drying, 6.82g (36.0 mmol) $Zn(NO_3)_2 \cdot 6H_2O$ and 18.73g (80.5 mmol) $Cu(NO_3)_2 \cdot 2.5H_2O$ dissolved into 40 mL of distilled water was added slowly to the catalyst. The catalyst was stirred as the solution was added to evenly distribute the solution over the material. The solid was then dried overnight at 120°C under N_2 .

COMPARATIVE EXAMPLE A

A copper/zinc/chromium catalyst was made as a comparative catalyst.

Copper Nitrate (36.42g), chromium nitrate (10.11g), and zinc nitrate (6.82g) were added to 100 mL of deionized water. The



the cake was washed with 4 litre of deionized water and vacuum dried for 2 days. The solid cake was then sieved to 40-20 mesh for use in the flow reactor.

COMPARATIVE EXAMPLE B

10 A copper/zinc on alumina catalyst was made as a comparative catalyst.

A 20 mL solution containing zinc nitrate (4.85g) and copper nitrate (10.72g) was slowly added to 36.12g of neutral γ -Alumina with a surface area of $120 \text{ m}^2/\text{g}$ (AX-200 from Criterion Catalyst Co., L.P.). The resulting catalyst was then dried at 150°C under vacuum for 24 hours.

COMPARATIVE EXAMPLE C

A copper/zinc/potassium on carbon catalyst was made as a comparative catalyst.

20 A solution of 2.09g potassium carbonate and 20 mL of distilled water was slowly added to 35g of dried CAL (Activated Carbon from Calgon). The catalyst was then dried at 80°C under vacuum. After cooling to room temperature, an aqueous solution (30mL) containing zinc nitrate (5.8g) and copper nitrate (15.0g) was added slowly with stirring. The catalyst was then dried at 80°C under vacuum.

EXAMPLE 2

This example demonstrates preparation of another dehydrogenation catalyst useful in the inventive process.

30 A 15.3g portion of the above catalyst from Comparative Example B was treated with an aqueous (10mL) potassium carbonate (0.65g) solution. The catalyst was then dried at 150°C under vacuum.

EXAMPLE 3

This example demonstrates preparation of another dehydrogenation catalyst useful in the inventive process.

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After drying, a 40 mL aqueous solution containing 6.77g of zinc nitrate and 14.98g of copper nitrate was slowly added to the catalyst. The catalyst was then dried overnight at 100°C under vacuum.

EXAMPLE 4

This example demonstrates preparation of another dehydrogenation catalyst useful in the inventive process.

A 30 mL aqueous solution containing 4.08g of potassium carbonate was slowly added to 50.2g of neutral γ -Alumina with a surface area of 120 m²/g (AX-200 from Criterion Catalyst Co., L.P.). The mixture was allowed to sit for 30 minutes to allow the solution to penetrate all of the catalyst. The excess water was then removed by heating at 100°C. The catalyst was then impregnated with 6.82 g zinc nitrate and 18.73g of copper nitrate dissolved in 40 mL of water. The sample was then dried overnight at 120°C under vacuum.

Catalyst Activation

Each of the above catalyst were activated in a similar manner. The catalyst was loaded into a stainless steel flow reactor atop of a 10-15 cm bed of silicon carbide. The temperature was slowly raised to 375°C while the reactor is purged with air. After all of the nitrate salts have decomposed (2 hours), the reactor is cooled to 150°C. At 150°C, the air flow is stopped and a 1:5 hydrogen/nitrogen gas is introduced into the reactor. The temperature is then slowly increased to 275°C at a rate of 0.5°C per minute.

Examples 5-8 and Comparative Examples D-F

This example demonstrates preparation of 2-para-dioxanone from diethylene glycol according to the inventive process using catalysts from Examples 1, 2, 3 and 4 respectively Examples 5, 6, 7 and 8. Further, 2-para-dioxanone was prepared using catalysts from

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table 1. A stainless steel flow reactor was charged with catalyst from the respective Examples between silicon carbide and glass wool layers (at the ends). The reactor was installed on a Lindberg furnace and connected to a nitrogen, hydrogen and feed lines on the top of the reactor. An outlet from the reactor was fitted with a sample receiver connected to the vent with a gas flow meter in line.

Nitrogen gas flow as adjusted to 250 mL min⁻¹ and the temperature raised to 120°C for 1 hour. After all the water has come off, the temperature was raised stepwise to 150°C and 50°C every 30 minutes thereafter or slowly ramped until reaching the final temperature listed in Table 1.

The reactor was cooled down to room temperature, and the hydrogen flow adjusted to 50 mL min⁻¹ for a total hydrogen and nitrogen gas flow of listed in Table 1. The catalyst bed was then slowly heated at 0.5°C per minute to 275°C.

The feed pump was started at 0.20 mL min⁻¹ and samples were collected every hour (1-4 hours) to confirm acceptable conversion and selectivity by GC-MS analysis.

For Example 5, catalyst was regenerated by first stopping the flow of feed over the catalyst and cooling to room temperature. The nitrogen/hydrogen sweep was stopped and air was flowed over the catalyst as the temperature is raised to 450°C at a rate of 0.1 to 1°C per minute. The catalyst is then cooled to room temperature, the sweeping gas is switched to nitrogen/hydrogen gas and the temperature is raised to 275°C at a rate of 0.1 to 1°C per minute. The catalyst was regenerated when the conversion dropped below 88%. The reactor ran continuously for 140 hours at 100% conversion and 96-99% selectivity to 2-para-dioxanone. Major side product identified was 1,4-dioxane.

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regenerating the catalyst. The conditions of reaction (amount of catalyst, LHSV, total hydrogen and nitrogen gas flow, and temperature) are listed in Table 1 below.

Percent conversion and selectivity are listed in Table 1 below.

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TABLE 1

	Catalyst Amount (ml)	Conditions			Results			
		LHSV	Flow ml/min	Temp °C	% Conversion	% PDX ^a	% Selectivity % Dioxane % HOAC ^b	Comment
Example 5	35	0.5	300	350	100	96-99	> 1	> 1
Example 6	20	0.90	200	250	82.0	73.7	2.6	3.8 A
"	"	0.30	"	"	81.9	76.4	3.3	B
"	"	0.90	"	300	93.1	87.0	2.8	1.8
Example 7	40	0.60	300	279	99.6	95.8	2.4	0.3
Example 8	35	0.34	300	280	100.0	97.7	1.0	0.4
Comp. Ex D	15	0.40	380	300	14.3	5.5		
"	"	"	"	350	48.1	20.5	4.5	3.2
Comp. Ex E	20	0.30	250	250	100.0	11.3	47.5	6.6 C
"	"	0.90	"	"	100.0	56.5	25.9	4.7 D
"	"	1.20	"	"	95.0	52.7	27.0	E
Comp. Ex F	35	0.69	300	250	89.7	19.0	1.2	16.0
^a - 2-para-dioxanone ^b - Acetic acid								
A - Dioxanol 2.5%								
B - Dioxanol 2.1%								
C - Dioxene 3.9%								
D - Dioxene 6.9%								
E - Dioxene 14.7%								

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dehydrogenation of dialkylene glycols, which process comprises:

contacting a dialkylene glycol at a temperature within the range of 200°C to 400°C with an effective amount of a

5 dehydrogenation catalyst comprising catalytically effective amounts of a copper compound, a zinc compound and a promoter compound selected from the group consisting of salts, compounds and complexes of alkali metals and alkaline earth metals and mixtures thereof supported on an alumina.

10 2. The process of claim 1 wherein the dialkylene glycol is contacted with the catalyst at a temperature of less than 300°C.

3. The process of claim 1 or 2 wherein the promoter compound is selected from the group consisting of salts, compounds and complexes of sodium, potassium, lithium, calcium, magnesium and mixtures thereof.

15 4. The process of claim 3 wherein the promoter is potassium, carbonate or potassium bicarbonate.

5. The process of any one of claims 1-4 wherein the zinc compound is present in a mole ratio of zinc to copper of about 0.01:1 to about 1.5:1.

20 6. The process of any one of claims 1-5 wherein the copper compound is present as measured as the metal in an amount of 1 weight percent to 35 weight percent based on the dehydrogenation catalyst.

25 7. The process of any one of claims 1-6 wherein the promoter compound is present as measured as the metal is an amount of 0.1 to 20 weight percent based on dehydrogenation catalyst.

8. The process of any one of claims 1-7 wherein the dehydrogenation catalyst further comprises a chromium compound.

30 9. The process of any one of claims 1-8 wherein the dehydrogenation catalyst is produced by (a) impregnating an alumina with a promoter selected from the group consisting of alkali metal



dehydrogenation catalyst, (d) calcining the dehydrogenation catalyst at a temperature within the range of from 100°C to 900°C, and (e) reducing the calcined dehydrogenation catalyst to activate the dehydrogenation catalyst.

10 10. The process of any one of claims 1-9 wherein the copper compound is selected from the group consisting of copper nitrate, copper acetate, copper oxide, copper oxalate, copper sulfate and copper chloride.

15 11. The process of any one of claims 1-10 wherein the zinc compound is selected from the group consisting of zinc nitrate, zinc acetate, zinc oxide, zinc oxalate, zinc sulfate and zinc chloride.

12. The process of any one of claims 1-11 wherein the dialkylene glycol is contacted with the dehydrogenation catalyst at a liquid hourly space velocity within the range of from 0.1 h^{-1} to 8 h^{-1} .

20 13. The process of any one of claims 1-12 which comprises:
contacting diethylene glycol with a dehydrogenation catalyst at a temperature within the range of about 250°C to about 300°C and at a liquid hourly space velocity within the range from about 0.5 h^{-1} to about 3 h^{-1} , said dehydrogenation catalyst is produced
25 by (a) impregnating a γ -alumina with a potassium compound, (b) subjecting the thus-impregnated alumina to a temperature within the range of about 80°C to about 900°C, (c) impregnating at least one zinc compound and at least one copper compound on the alumina from step (b) to form a dehydrogenation catalyst, (d) calcining the
30 dehydrogenation catalyst at a temperature within the range of from 100°C to 900°C, and (e) contacting the calcined dehydrogenation catalyst with a reducing atmosphere comprising a gas selected from the group consisting of hydrogen, ammonia, carbon dioxide and mixture thereof at a temperature within the range of about 175°C to
35 about 550°C.





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PROCESS FOR PREPARING 2-PARA-DIOXANONES

The invention relates to a process a process for preparing 2-para-dioxanones by the catalytic dehydrogenation of dialkylene glycols, which process comprises:

contacting a dialkylene glycol at a temperature within the range of 200°C to 400°C with an effective amount of a dehydrogenation catalyst comprising catalytically effective amounts of a copper compound, a zinc compound and a promoter compound selected from the group consisting of salts, compounds and complexes of alkali metals and alkaline earth metals and mixtures thereof supported on an alumina and to the dehydrogenation catalyst used.

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This invention relates to a process for preparing 2-paradioxanones. In a specific aspect, the invention relates to a process for preparing 2-para-dioxanones by the catalytic dehydrogenation of dialkylene glycols, and to the dehydrogenation catalyst used.

2-Para-dioxanones are used as a starting material in the manufacture of poly(2-para-dioxanones). The poly 2-para-dioxanones are used in the manufacture of adsorbable monofilament suture fibres and other adsorbable medical devices.

One method of preparing 2-para-dioxanones is by oxidative dehydrogenation of dialkylene glycols. In U.S. Patent Nos. 2,900,395 and 2,807,629, a copper chromite catalyst is used for the oxidative dehydrogenation of diethylene glycol. However, these patents report a yield of about 67-84% and a conversion of about 67-94%.

It has been found that the presence of impurities inhibit polymerization. Typical impurities in the preparation of 2-para-dioxanone include, unreacted dialkylene glycol and reaction by-products such as 2-para-dioxanol, para-dioxane, 2,3-dihydro-para-dioxin (dioxene), alkylene glycol and carboxylic acids. Particularly, the production of carboxylic acids and hydroxylic compounds can hinder polymerization of 2-para-dioxanones. Therefore, a process to produce a high purity 2-para-dioxanone ("polymerization grade") is desirable.

It is therefore an object of the present invention to provide a 2-para-dioxanone preparation process with high conversion rate and selectivity.

According to the invention, a process for the

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amount of a dehydrogenation catalyst comprising catalytically effective amounts of a copper compound, a zinc compound and a promoter compound selected from the group consisting of salts, compounds and complexes of alkali metals and alkaline earth metals and mixtures thereof supported on an alumina.

It has been found that 2-para-dioxanones can be produced in high yields with minimal side-reactions by contacting a dialkylene glycol with an effective amount of a dehydrogenation catalyst. Further, it has been found that by preferably impregnating the alumina with a promoter prior to metal mixture impregnation, a dehydrogenation catalyst which has conversion as high as about 100% and/or selectivity as high as about 98% can be obtained.

Suitable promoters can be compounds (including, salts, compounds and complexes) of alkali metals and alkaline earth metals. The promoters must be soluble in a suitable solubilizing media, either organic or inorganic. Water is a preferred solubilizing media. Lower alkanols and ethers also provide examples of suitable organic solvents. Preferred promoters include, for example, compounds of sodium, potassium, lithium, calcium, magnesium and mixtures thereof. The promoter is typically present in an amount sufficient to suppress para-dioxane formation. The promoter is preferably present in an amount of from 0.1 to 20 weight percent, more preferably from 0.5 to 10 weight percent measured as the metal per total weight of the dehydrogenation catalyst. The optimum catalyst contains 1 to 5 weight percent of promoter measured as the metal per total

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100 m²/g is preferred. An alumina with a lower surface area than 100 m²/g is also acceptable, however, activity decreases with decreasing surface area while maintaining the selectivity level of the dehydrogenation catalyst. The B.E.T. method for determining specific surface area is described in detail in Brunauer, S., Emmet, P. H., and Teller, E.J., J. Am. Chem. Soc., 60, 309-16 (1938). The most suitable aluminas for use in the present invention are found to be those having a high surface area of, for instance, at least 100 m²/g. The alumina may contain minor amounts of other compounds such as silica (i.e., less than 50 weight percent). Large amounts of silica increases the presence of impurities in the reaction product and should be avoided. Suitable commercial aluminas include, Vista Catapal Series; AX-200 type from Criterion Catalyst Co., L.P.; and A-201 from La Roche Aluminas.

The dehydrogenation catalyst can be prepared by impregnating the alumina support with solubilized compounds (including, salts, compounds and complexes) of copper, zinc, a promoter, and optionally chromium. The impregnation can be carried out in any order or simultaneously. In a preferred embodiment, the promoter is first impregnated on the alumina support, then dried and optionally calcined. The dried (and calcined) material is then impregnated with a solution having copper, zinc and optionally chromium compounds dissolved therein. The alumina can be impregnated in a one-step process by using a single solution copper, zinc and optionally chromium compounds or in a multi-step process, using one or more of copper, zinc and optionally chromium

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filled and no excess solution is left after impregnation.

The alkali and alkaline earth promoters can be impregnated on alumina in the form of compounds (including, salts, compounds and complexes) such as, for example, hydroxides, chlorides, bromides, nitrates, acetates, lactates, carbonates, bicarbonates, oxides, oxalates, sulfates and the like. Carbonates and bicarbonates are preferred because of ease of use. Suitable copper, zinc and chromium compounds includes, for example, chlorides, bromides, nitrates, acetates, lactates, carbonates, bicarbonates, oxides, oxalates, sulfates and the like. Nitrates are preferred for ease of decomposition.

This material after impregnation with catalytic components is dried and calcined. The drying step is typically carried out at temperatures up to 150°C, preferably at a temperature within the range of from 80°C to 150°C. The calcination step is typically carried out at a temperature within the range of from 100°C to 900°C, preferably from 300°C to 800°C. The drying and calcining steps can be carried out in one continuous step, heating the material slowly through the low temperature ranges to dry the material and then raising the temperature to the calcining conditions. The drying step is preferably carried out in the initial stages of the calcination step if the alumina is calcined. The impregnated material is calcined to convert the soluble metal compounds to oxides or oxygen-containing compounds upon the alumina support. Calcining is carried out in a neutral or oxidizing atmosphere, air being the preferred atmosphere. Nitrogen is also a suitable alternative atmosphere. The times for

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acceptable.

The calcined material is then activated by subjecting the catalyst to a reducing condition prior to use. The reducing condition may be either a gaseous atmosphere or a suitable liquid solution.

Suitable examples of a gaseous reducing atmosphere comprise hydrogen, ammonia, carbon monoxide, mixtures thereof and the like. The gaseous reducing atmosphere may also optionally contain inert gases such as nitrogen. The preferred atmosphere is hydrogen. Activation temperatures when utilizing a gaseous atmosphere range from 175°C to 550°C. The time needed for activation in a gaseous atmosphere will depend on the temperature, the higher the temperature, the shorter the time and the lower the temperature, the longer the activation. Typically, useful times have been found to range from 0.01 hour to 24 hours. Although times outside these limits are also useful, economic considerations generally dictate that longer times need not be used. It is preferable, after conversion of the metal compounds to the oxides, to slowly ramp the temperature (eg. 0.1 to 2°C per minute) up to the activation temperature in the presence of reducing atmosphere. This procedure increase the lifetime of the catalyst.

Liquid solutions suitable for providing reducing conditions include, for example, aqueous or ammoniacal solutions of hydrazine, sodium borohydride or formaldehyde or solutions of triethyl aluminium or diisobutyl aluminium hydride in an organic solvent such as heptane. The catalysts can be activated using reducing liquid solutions within a range of from 25°C or higher,

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While not wishing to be bound by any particular theory, it is believed that the activation of the catalyst under reducing conditions at least partially reduces the copper from the +2 valence state to the +1 and/or 0 valence state, which is believed to contribute to the catalytic activity of the catalyst. Reducing conditions, however, preferably should not be so severe as to reduce the zinc oxides and chromium oxides. Preferably, the promoters are present on the catalyst in the oxidized form, even after subjecting to reducing conditions. They are believed to be present in the form of oxides or oxygen-containing compounds and may be combined with the alumina support and/or other catalyst components.

The appropriate activation conditions can readily be determined by experimentation. For example, times and temperatures can be varied and the resultant catalytic material can be examined by x-ray photoelectron spectroscopy in order to determine the activation state of the copper. Alternatively, the catalyst's catalytic activity can be determined and utilized to determine optimum activating conditions.

The amount of metals deposited upon the support are not critical and may be varied through a wide range so long as they are present in sufficient amount to be catalytically effective. Preferably copper is present in an amount of 1 to 35 weight percent, more preferably 1 to 15 weight percent measured as metal per total weight of the dehydrogenation catalyst. Preferably zinc is present in a mole ratio of zinc to copper of from 0.01:1 to 5:1, more preferably from 0.01:1 to 1.5:1. Chromium can

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optionally alkyl-substituted 2-para-dioxanone is contacted, in a reaction zone, with an effective amount of a dehydrogenation catalyst (prepared as described above) to produce the 2-para-dioxanone at a temperature within the range of from 200°C to 400°C, preferably from 250°C to 300°C. A temperature of less than 300°C is preferred for longer catalyst life. The reaction is carried out at a pressure within the range of 10 to 2000 kPa (0.1 to 20 atmosphere), preferably from 50 to 500 kPa (0.5 to 5 atmosphere).

In a particularly preferred embodiment, the dehydrogenation catalyst preferably does not contain chromium for environmental disposal reasons. For longer catalyst life-time, dehydrogenation catalysts having a relatively higher copper loading, for instance, alumina having copper in the amount of at least 4 weight percent measured as metal per total weight of the dehydrogenation catalyst is preferred. Promoter is preferably present in an amount of less than 15 weight percent measured as metal per total weight of the dehydrogenation catalyst to minimize side-reactions.

The inventive process can be carried out in vapour phase, liquid phase or can be refluxed in the presence of the dehydrogenation catalyst. The reaction is preferably carried out neat, but can be in an inert solvent or environment. The process can further be carried out in a batch process or in a continuous process.

In a continuous process, the liquid hourly space velocity (LHSV) at the reaction zone is at a rate effective to form 2-para-dioxanones, preferably within the range of from 0.1 to 8 h⁻¹, more preferably from 0.1

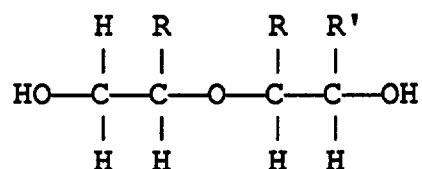
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be suitable. Currently, the reaction is more preferably carried out in an inert gas/hydrogen atmosphere containing hydrogen to inert gas ratio from 1:0.01 to 1:50. In a particularly preferred embodiment, the process is carried out continuously at a temperature in the range of from 260°C to 290°C, a pressure in the range of from 50 to 200 kPa (0.5 to 2 atmosphere) and a LHSV within the range of from about 0.5 to 2 h⁻¹. The process can be carried out in fluidized beds or packed columns, with packed columns being preferred due to ease of operation.

In a batch process, the catalyst is present in an amount effective to form 2-para-dioxanones, preferably in an amount of from 0.1 weight percent to 50 weight percent, more preferably from 1 weight percent to 20 weight percent based on the weight of the dialkylene glycol.

Suitable dialkylene glycol can be represented by the formula



in which each R and R' are independently hydrogen or C₁₋₂₀ alkyl. Preferably R' is hydrogen. Preferably R is independently hydrogen or C₁₋₁₂, most preferably hydrogen or C₁₋₂. Examples of the most preferable dialkylene glycols include, diethylene glycol, dipropylene glycol and dibutylene glycol. The inventive process is especially suitable for production of 2-para-dioxanone by the dehydrogenation of diethylene glycol.

The dehydrogenation catalyst can be regenerated after

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regenerated in situ or removed from the reactor and regenerated separately.

The catalyst can be regenerated by heating the catalyst at a temperature within the range of 100°C to 900°C, preferably from 300°C to 800°C in a neutral or oxidizing atmosphere, air being the preferred atmosphere. Nitrogen or oxygen or a mixture thereof are also suitable atmosphere. For example, in a continuous process, the catalyst can be regenerated in situ by first stopping the flow of the feed over the catalyst and cooling the catalyst to about room temperature. Then the catalyst can be regenerated by contacting the catalyst in a neutral or oxidizing atmosphere at an elevated temperature with a flow of the atmosphere. After the catalyst is regenerated, the catalyst is reactivated prior to use.

The inventive process allows formation of highly pure 2-para-dioxanone with minimal side-reactions. Impurities such as carboxylic acids, hydroxylic compounds and dioxane are minimized while obtaining high conversion and selectivity.

The following illustrative embodiments describe the process of the invention and are provided for illustrative purposes and are not meant as limiting the invention.

EXAMPLE 1

This example demonstrates preparation of a dehydrogenation catalyst according to the inventive process.

A solution of 2.04g (13.3 mmol) K_2CO_3 in 30 mL of distilled water was added slowly to 50.20g of neutral

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dissolved into 40 mL of distilled water was added slowly to the catalyst. The catalyst was stirred as the solution was added to evenly distribute the solution over the material. The solid was then dried overnight at 120°C under N₂.

COMPARATIVE EXAMPLE A

A copper/zinc/chromium catalyst was made as a comparative catalyst.

Copper Nitrate (36.42g), chromium nitrate (10.11g), and zinc nitrate (6.82g) were added to 100 mL of deionized water. The resulting solution was heated to 90°C and added to a stirred aqueous (600 mL) solution of potassium carbonate (30.63g), also at 90°C. The resulting mixture was allowed to cool to room temperature with stirring, before the solids were filtered off. The cake was washed with 4 litre of deionized water and vacuum dried for 2 days. The solid cake was then sieved to 40-20 mesh for use in the flow reactor.

COMPARATIVE EXAMPLE B

A copper/zinc on alumina catalyst was made as a comparative catalyst.

A 20 mL solution containing zinc nitrate (4.85g) and copper nitrate (10.72g) was slowly added to 36.12g of neutral γ -Alumina with a surface area of 120 m²/g (AX-200 from Criterion Catalyst Co., L.P.). The resulting catalyst was then dried at 150°C under vacuum for 24 hours.

COMPARATIVE EXAMPLE C

A copper/zinc/potassium on carbon catalyst was made as a comparative catalyst.

A solution of 2.09g potassium carbonate and 20 mL of

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nitrate (5.8g) and copper nitrate (15.0g) was added slowly with stirring. The catalyst was then dried at 80°C under vacuum.

EXAMPLE 2

This example demonstrates preparation of another dehydrogenation catalyst useful in the inventive process.

A 15.3g portion of the above catalyst from Comparative Example B was treated with an aqueous (10mL) potassium carbonate (0.65g) solution. The catalyst was then dried at 150°C under vacuum.

EXAMPLE 3

This example demonstrates preparation of another dehydrogenation catalyst useful in the inventive process.

A solution of 4.01g of potassium carbonate was dissolved in 60 mL of water and slowly added to 50.35g of neutral γ -Alumina with a surface area of 120 m²/g (AX-200 from Criterion Catalyst Co., L.P.). The excess water was then removed by heating at 100°C. After drying, a 40 mL aqueous solution containing 6.77g of zinc nitrate and 14.98g of copper nitrate was slowly added to the catalyst. The catalyst was then dried overnight at 100°C under vacuum.

EXAMPLE 4

This example demonstrates preparation of another dehydrogenation catalyst useful in the inventive process.

A 30 mL aqueous solution containing 4.08g of potassium carbonate was slowly added to 50.2g of neutral γ -Alumina with a surface area of 120 m²/g (AX-200 from Criterion Catalyst Co., L.P.). The mixture was allowed to sit for 30 minutes to allow the solution to penetrate all of the catalyst. The excess water was then removed

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Catalyst Activation

Each of the above catalyst were activated in a similar manner. The catalyst was loaded into a stainless steel flow reactor atop of a 10-15 cm bed of silicon carbide. The temperature was slowly raised to 375°C while the reactor is purged with air. After all of the nitrate salts have decomposed (2 hours), the reactor is cooled to 150°C. At 150°C, the air flow is stopped and a 1:5 hydrogen/nitrogen gas is introduced into the reactor. The temperature is then slowly increased to 275°C at a rate of 0.5°C per minute.

Examples 5-8 and Comparative Examples D-F

This example demonstrates preparation of 2-para-dioxanone from diethylene glycol according to the inventive process using catalysts from Examples 1, 2, 3 and 4 respectively Examples 5, 6, 7 and 8. Further, 2-para-dioxanone was prepared using catalysts from Comparative Examples A, B and C, respectively Comparative Examples D, E and F.

For all of the Examples, the following procedure was used using the catalyst amounts and reactor conditions listed in Table 1. A stainless steel flow reactor was charged with catalyst from the respective Examples between silicon carbide and glass wool layers (at the ends). The reactor was installed on a Lindberg furnace and connected to a nitrogen, hydrogen and feed lines on the top of the reactor. An outlet from the reactor was fitted with a sample receiver connected to the vent with a gas flow meter in line.

Nitrogen gas flow as adjusted to 250 mL min⁻¹ and the temperature raised to 120°C for 1 hour. After all the

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The reactor was cooled down to room temperature, and the hydrogen flow adjusted to 50 mL min⁻¹ for a total hydrogen and nitrogen gas flow of listed in Table 1. The catalyst bed was then slowly heated at 0.5°C per minute to 275°C.

The feed pump was started at 0.20 mL min⁻¹ and samples were collected every hour (1-4 hours) to confirm acceptable conversion and selectivity by GC-MS analysis.

For Example 5, catalyst was regenerated by first stopping the flow of feed over the catalyst and cooling to room temperature. The nitrogen/hydrogen sweep was stopped and air was flowed over the catalyst as the temperature is raised to 450°C at a rate of 0.1 to 1°C per minute. The catalyst is then cooled to room temperature, the sweeping gas is switched to nitrogen/hydrogen gas and the temperature is raised to 275°C at a rate of 0.1 to 1°C per minute. The catalyst was regenerated when the conversion dropped below 88%. The reactor ran continuously for 140 hours at 100% conversion and 96-99% selectivity to 2-para-dioxanone. Major side product identified was 1,4-dioxane.

For Examples 6-8 and Comparative Examples D-F, 2-dioxanone was prepared in a similar manner to Example 5, except, catalyst from Examples 2-4 and Comparative Examples A-C were used, respectively. All of the other Examples were run between 200 to 800 hours without regenerating the catalyst. The conditions of reaction (amount of catalyst, LHSV, total hydrogen and nitrogen gas flow, and temperature) are listed in Table 1 below.

Percent conversion and selectivity are listed in Table 1 below.

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Catalyst		Conditions			Results		
Amount							
(ml)		Flow	Temp	%	% Selectivity		
		LHSV ml/min	°C	Conversion	% PDX ^a	% Dioxane	% HOAC ^b
Example 5	35	0.5	300	350	100	96-99	> 1
Example 6	20	0.90	200	250	82.0	73.7	2.6
"	"	0.30	"	"	81.9	76.4	3.3
"	"	0.90	"	300	93.1	87.0	2.8
Example 7	40	0.60	300	279	99.6	95.8	2.4
Example 8	35	0.34	300	280	100.0	97.7	1.0
Comp. Ex D	15	0.40	380	300	14.3	5.5	0.4
"	"	"	"	350	48.1	20.5	4.5
Comp. Ex E	20	0.30	250	250	100.0	11.3	47.5
"	"	0.90	"	"	100.0	56.5	25.9
"	"	1.20	"	"	95.0	52.7	27.0
Comp. Ex F	35	0.69	300	250	89.7	19.0	1.2
A - Dioxanol 2.5%		a - 2-para-dioxanone					
B - Dioxanol 2.1%		b - Acetic acid					
C - Dioxene 3.9%							
D - Dioxene 6.9%							
E - Dioxene 14.7%							

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1. A process for preparing 2-para-dioxanones by the catalytic dehydrogenation of dialkylene glycols, which process comprises:

contacting a dialkylene glycol at a temperature within the range of 200°C to 400°C with an effective amount of a dehydrogenation catalyst comprising catalytically effective amounts of a copper compound, a zinc compound and a promoter compound selected from the group consisting of salts, compounds and complexes of alkali metals and alkaline earth metals and mixtures thereof supported on an alumina.

2. The process of claim 1 wherein the dialkylene glycol is contacted with the catalyst at a temperature of less than 300°C.

3. The process of claim 1 or 2 wherein the promoter compound is selected from the group consisting of salts, compounds and complexes of sodium, potassium, lithium, calcium, magnesium and mixtures thereof.

4. The process of claim 3 wherein the promoter is potassium, carbonate or potassium bicarbonate.

5. The process of any one of claims 1-4 wherein the zinc compound is present in a mole ratio of zinc to copper of about 0.01:1 to about 1.5:1.

6. The process of any one of claims 1-5 wherein the copper compound is present as measured as the metal in an amount of 1 weight percent to 35 weight percent based on the dehydrogenation catalyst.

7. The process of any one of claims 1-6 wherein the promoter compound is present as measured as the metal is an amount of 0.1 to 20 weight percent based on dehydrogenation catalyst.

8. The process of any one of claims 1-7 wherein the

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an alumina with a promoter selected from the group consisting of alkali metal compounds and alkaline earth metal compounds, (b) subjecting the thus-impregnated alumina to a temperature within the range of from 80°C to 900°C, (c) impregnating at least one zinc compound and at least one copper compound on the alumina from step (b) to form a dehydrogenation catalyst, (d) calcining the dehydrogenation catalyst at a temperature within the range of from 100°C to 900°C, and (e) reducing the calcined dehydrogenation catalyst to activate the dehydrogenation catalyst.

10. The process of any one of claims 1-9 wherein the copper compound is selected from the group consisting of copper nitrate, copper acetate, copper oxide, copper oxalate, copper sulfate and copper chloride.

11. The process of any one of claims 1-10 wherein the zinc compound is selected from the group consisting of zinc nitrate, zinc acetate, zinc oxide, zinc oxalate, zinc sulfate and zinc chloride.

12. The process of any one of claims 1-11 wherein the dialkylene glycol is contacted with the dehydrogenation catalyst at a liquid hourly space velocity within the range of from 0.1 h⁻¹ to 8 h⁻¹.

13. The process of any one of claims 1-12 which comprises:

contacting diethylene glycol with a dehydrogenation catalyst at a temperature within the range of about 250°C to about 300°C and at a liquid hourly space velocity within the range from about 0.5 h⁻¹ to about 3 h⁻¹, said dehydrogenation catalyst is produced by (a) impregnating a γ -alumina with a potassium compound, (b) subjecting the thus-impregnated alumina to a temperature within the

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temperature within the range of from 100°C to 900°C, and
(e) contacting the calcined dehydrogenation catalyst with
a reducing atmosphere comprising a gas selected from the
group consisting of hydrogen, ammonia, carbon dioxide and
mixture thereof at a temperature within the range of
about 175°C to about 550°C.

14. A dehydrogenation catalyst as defined by any one of
claims 1-13.

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The invention relates to a process a process for preparing 2-para-dioxanones by the catalytic dehydrogenation of dialkylene glycols, which process comprises:

contacting a dialkylene glycol at a temperature within the range of 200°C to 400°C with an effective amount of a dehydrogenation catalyst comprising catalytically effective amounts of a copper compound, a zinc compound and a promoter compound selected from the group consisting of salts, compounds and complexes of alkali metals and alkaline earth metals and mixtures thereof supported on an alumina and to the dehydrogenation catalyst used.

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1. A process for preparing 2-para-dioxanones by the catalytic dehydrogenation of dialkylene glycols, which process comprises:

contacting a dialkylene glycol at a temperature within the range of 200 °C to 400 °C with an effective amount of a dehydrogenation catalyst comprising catalytically effective amounts of a copper compound, a zinc compound and a promoter compound selected from the group consisting of salts, compounds and complexes of alkali metals and alkaline earth metals and mixtures thereof supported on an alumina.

2. The process of claim 1 wherein the dialkylene glycol is contacted with the catalyst at a temperature of less than 300 °C.

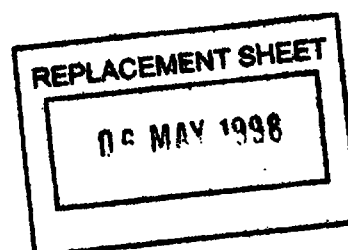
3. The process of claim 1 or 2 wherein the promoter compound is selected from the group consisting of salts, compounds and complexes of sodium, potassium, lithium, calcium, magnesium and mixtures thereof.

4. The process of claim 3 wherein the promoter is potassium, carbonate or potassium bicarbonate.

5. The process of any one of claims 1-4 wherein the zinc compound is present in a mole ratio of zinc to copper of about 0.01:1 to about 1.5:1.

6. The process of any one of claims 1-5 wherein the copper compound is present as measured as the metal in an amount of 1 weight percent to 35 weight percent based on the dehydrogenation catalyst.

7. The process of any one of claims 1-6 wherein the promoter compound is present as measured as the metal is



compound.

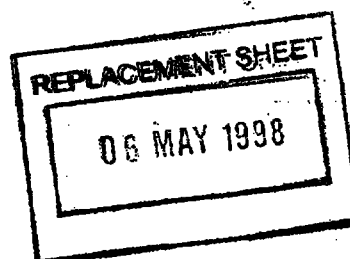
9. The process of any one of claims 1-8 wherein the dehydrogenation catalyst is produced by (a) impregnating an alumina with a promoter selected from the group consisting of alkali metal compounds and alkaline earth metal compounds, (b) subjecting the thus-impregnated alumina to a temperature within the range of from 80 °C to 150 °C, (c) impregnating at least one zinc compound and at least one copper compound on the alumina from step (b) to form a dehydrogenation catalyst, (d) calcining the dehydrogenation catalyst at a temperature within the range of from 100 °C to 900 °C, and (e) reducing the calcined dehydrogenation catalyst to activate the dehydrogenation catalyst.

10. The process of any one of claims 1-9 wherein the copper compound is selected from the group consisting of copper nitrate, copper acetate, copper oxide, copper oxalate, copper sulfate and copper chloride.

11. The process of any one of claims 1-10 wherein the zinc compound is selected from the group consisting of zinc nitrate, zinc acetate, zinc oxide, zinc oxalate, zinc sulfate and zinc chloride.

12. The process of any one of claims 1-11 wherein the dialkylene glycol is contacted with the dehydrogenation catalyst at a liquid hourly space velocity within the range of from 0.1 h⁻¹ to 8 h⁻¹.

13. The process of any one of claims 1-12 which comprises:



3 h⁻¹, said dehydrogenation catalyst is produced by (a) impregnating a c-alumina with a potassium compound, (b) subjecting the thus-impregnated alumina to a temperature within the range of about 80 °C to about 150 °C, (c) impregnating at least one zinc compound and at least one copper compound on the alumina from step (b) to form a dehydrogenation catalyst, (d) calcining the dehydrogenation catalyst at a temperature within the range of from 100 °C to 900 °C, and (e) contacting the calcined dehydrogenation catalyst with a reducing atmosphere comprising a gas selected from the group consisting of hydrogen, ammonia, carbon dioxide and mixture thereof at a temperature within the range of about 175 °C to about 550 °C.

14. The process of any one of claims 1-13 wherein the dehydrogenation catalyst is regenerated after or during use to extend the catalyst life.

15. The process of any one of claims 1-14 wherein the reaction is carried out at a pressure of 10 to 2000 kPa.



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