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**LOW PRESSURE PROCESS FOR THE
HYDROGENATION OF DIMETHYL BENZENEDICARBOXYLATES TO
THE CORRESPONDING DIMETHYL CYCLOHEXANEDICARBOXYLATES**

5 This invention pertains to an improved process for
the preparation of dimethyl cyclohexanedicarboxylates by
the hydrogenation of the analogous dimethyl benzenedi-
carboxylate ester. More specifically, the present
invention pertains to an improved process for the
10 hydrogenation of a dimethyl benzenedicarboxylate ester
in the presence of certain, supported, bimetallic
catalysts comprising (i) palladium, (ii) a second Group
VIII metal selected from nickel, platinum and ruthenium
and (iii) a catalyst support material. The use of the
15 supported bimetallic catalysts permit the use of
significantly lower process pressures in the ester
hydrogenation process.

 Dimethyl 1,4-cyclohexanedicarboxylate has been
manufactured for over 30 years as an intermediate in the
20 production of cyclohexanedimethanol which is used
extensively as a monomer in the preparation of conden-
sation polymers, particularly polyesters. Dimethyl
cyclohexanedicarboxylates are valuable chemical
intermediates useful, for example, in the manufacture of
25 polyester resins used in the formulation of coating
compositions.

 The manufacture of dimethyl 1,4-cyclohexanedicar-
boxylate and 1,4-cyclohexanedimethanol using dimethyl
terephthalate as the feedstock and a heterogenous mode
30 of operation is described in U.S. Patent 3,334,149.
This process requires the use of high pressures, e.g.,
greater than 346 bars absolute (34,600 kPa), and
utilizes a palladium on alumina catalyst in the
hydrogenation of dimethyl terephthalate to dimethyl
35 1,4-cyclohexanedicarboxylate. The specific palladium on



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alumina employed contains 0.5 weight percent palladium deposited on alumina, the crystalline phase of which is a mixture of bayerite and boehmite. The catalyst is used in the form of 3 mm chips and exhibits poor physical strength.

It is apparent that chemical processes which require the use of high pressures such as pressures in excess of 340 bars (34,000 kPa) are inherently expensive due to the increased operating costs and the cost of the apparatus required including the high pressure-rated reactor and the compressors. It has been found, however, that when the hydrogenation of dimethyl terephthalate to dimethyl 1,4-cyclohexanedicarboxylate is carried out at pressures less than 135 bars absolute (13,500 kPa) using the above-described palladium on alumina catalyst, commercially acceptable hydrogenation rates cannot be achieved over an extended period of time. For example, when operating continuously at 125 bars absolute (12,500 kPa) using the above-described catalyst, the process is unstable and the hydrogenation rate typically is not more than approximately 55% of the rates achieved at approximately 410 bars absolute (41,000 kPa) pressure. The reduced hydrogenation rate is due to decreased activity of the palladium catalyst which, we believe, is related to the generation of carbon monoxide during the hydrogenation at lower pressures. It is known that the presence of carbon monoxide in hydrogen gas used in hydrogenation processes is detrimental to such processes. However, the extreme sensitivity of the above-described palladium on alumina catalyst to parts per million (ppm) amounts of carbon monoxide is surprising.

The present invention is concerned with a process whereby dimethyl benzenedicarboxylates may be

catalytically hydrogenated to the corresponding dimethyl cyclohexanedicarboxylates using moderate pressures and readily available catalysts. We have discovered that acceptable rates at moderate pressures may be achieved by the use of a supported catalyst comprising palladium and a second Group VIII metal selected from nickel, platinum and ruthenium deposited on an alumina support wherein (1) the dispersion and depth of deposition of the palladium metal are within certain ranges, (2) the alumina is of a particular crystalline phase, and (3) the surface area of the catalyst is within a particular range. The process provided by our invention therefore provides a means for the preparation of a dimethyl cyclohexanedicarboxylate which comprises contacting a dimethyl benzenedicarboxylate with hydrogen at a temperature of 140 to 400°C and a pressure of 10 to 200 bars absolute (1,000 to 20,000 kPa) in the presence of a supported catalyst comprising palladium and a second Group VIII metal selected from nickel, platinum, ruthenium or a mixture thereof deposited on an alumina support; wherein

- (1) palladium comprises 0.1 to 5.0 weight percent of the catalyst;
- (2) the palladium dispersion is at least 15 percent;
- (3) at least 90 weight percent of the palladium is located on the alumina at a depth less than 200 microns from the surface of the alumina;
- (4) the second Group VIII metal selected from nickel, platinum, ruthenium or a mixture thereof comprises 0.001 to 1 weight percent of the catalyst; and
- (5) the crystalline phase of the alumina is alpha, theta, delta, gamma, eta or a mixture thereof.

The second Group VIII metal of the catalysts improves the catalytic activity as compared to the same supported palladium catalysts which do not contain a second metal.

5 The minimum temperature at which the process may be carried out is limited by the melting point of the dimethyl benzenedicarboxylate reactant, e.g., 140°C for dimethyl 1,4-benzenedicarboxylate (dimethyl terephthalate). The maximum operating temperature can be as high as 400°C. The process preferably is carried out at 10 a temperature in the range of 140 to 220°C. Although the process may be carried out at pressures in the range of 8 to 690 bars absolute (800 to 69,000 kPa), the present invention permits the achievement of good hydrogenation rates without the use of the high 15 pressures described in the literature. Thus, the preferred pressures are within the range of about 50 to 170 bars absolute (5,000 to 17,000 kPa). Although the 1,2-, 1,3- and 1,4-isomers of dimethyl cyclohexanedicarboxylate may be prepared by the process of this 20 invention by the hydrogenation of the analogous dimethyl benzenedicarboxylate, the primary usefulness of the process is in the manufacture of the 1,3- and, especially, the 1,4-isomers.

25 The catalyst used in the present invention comprises palladium and a second Group VIII metal deposited on an alumina support wherein:

- (i) the palladium comprises 0.1 to 5.0, preferably 0.5 to 2.0, weight percent based on the total weight of the catalyst; and
- 30 (ii) the second Group VIII metal selected from nickel, platinum, ruthenium or a mixture thereof comprises 0.001 to 1, preferably 0.01 to 0.5, weight percent based on the total weight of the catalyst.

The dispersion of the palladium on and in the alumina support typically is measured by titration of the surface of the support with carbon monoxide gas and measuring the amount of carbon monoxide adsorbed on the palladium surface. Normally, it is assumed that each surface metal atom will adsorb one molecule of carbon monoxide and thus, the percent of metal exposed may be determined. Metal dispersion also can be determined using hydrogen as the probe molecule. Hydrogen dissociates to 2 H atoms and each surface palladium atom absorbs 1 molecule of H atom. This percentage is known as the dispersion. See Myasaki, J. Catal., 65, 84 (1980) and "Structure of Metallic Catalysts" by J. R. Anderson, Academic Press, 1975, page 360. The catalysts which are advantageously used in accordance with the present invention have a dispersion percentage of at least 15 percent, preferably at least 30 percent (as determined by carbon monoxide or hydrogen adsorption as described herein).

Another characteristic of the palladium catalyst used in the present invention is that most of the palladium is located on or near the surface of the alumina support. Accordingly, at least 90 weight percent of the palladium is located no deeper than 200 microns, preferably less than 100 microns, from the external surface of the alumina support. As is well-known in the art, depth of impregnation can be determined either visually using optical microscopy or by a line scan technique in a SEM with a palladium sensitive detector. See, for example, the above-cited "Structure of Metallic Catalysts".

Yet another important characteristic of the catalysts is the crystalline phase of the alumina support which is selected from the alpha, theta, delta,

gamma, eta phases or a mixture of such crystalline phases. Alumina of theta, delta or alpha crystalline phases or mixture of such alumina is preferred with theta alumina being especially preferred.

5 The nitrogen BET surface area of the palladium on alumina catalysts used in the process of our invention is in the range of about 20 to 300 square meters per gram (m^2/g) with the range of about 30 to 150 m^2/g being preferred. It is well known in the art that BET surface
10 area is a function of crystalline phases and calcination history and should be as high as possible while maintaining the appropriate oxide phase. Catalysts having the characteristics described hereinabove may be prepared according to conventional impregnation or
15 deposition techniques using procedures well known to those skilled in the art. The catalyst may be used in the hydrogenation process in the form of pellets, spheres, extrudates and the like. The particular form is not critical so long as the catalyst form does not
20 lead to excessive channeling of the liquid feed through the reactor, e.g., in continuous operation using a fixed bed of catalyst through which the reactant is passed. Preferably, the surface area:volume ratio of the catalyst is at least 500 and preferably greater than
25 1500.

 The process of the invention may be carried out in a batch, semi-continuous or continuous mode using conventional chemical processing techniques. The preferred mode of operation is a continuous process
30 wherein a melt of a dimethyl benzenedicarboxylate is passed over and through one or more fixed beds of catalyst in a "trickle bed" manner. Typically, some of the dimethyl cyclohexanedicarboxylate product is recycled to the feed port of the reactor and serves as a

solvent for the reactant. Other inert, non-aromatic compounds which are liquid under the operating conditions employed may be used as a solvent. The process may be operated in either an adiabatic or isothermal fashion. In trickle bed operation, the liquid hourly space velocity (LHSV; unit volume reactant fed per hour per unit volume catalyst) of the reactant feed may be in the range of about 0.1 to 10 with a preferred range of 0.5 to 5. The LHSV for the total liquid flow (reactant plus solvent) may be in the range of 1 to 30. Hydrogen is fed to the reactor in excess of the stoichiometric quantity and normally is purged from the system. The rate of hydrogen purge is dependent on the temperature and pressure at which the process is operated.

Our novel process is further illustrated by the following examples. All experiments were performed in a trickle bed reactor system comprising a 1.83 meter (6 feet) section of 316 stainless steel pipe having an interior diameter of 2.5 cm (1 inch) and equipped with means for liquid recycle. The catalyst (800 cc) was held in place within the reactor by 100 cc of 1.6 mm (0.0625 inch) 316 stainless steel Penn State packing located above and below the catalyst bed. The temperatures at various points within the catalyst bed were measured by 10 thermocouples which extended through the reactor wall and approximately 3.2 mm into the catalyst. The temperature reported in each example is the average of these 10 readings. Typical temperature gradients through the bed were less than 10°C.

The procedure generally used in each experiment comprised purging the system with nitrogen and pumping dimethyl 1,4-cyclohexanedicarboxylate (DMCD) through the

reactor system at a rate of 5 Kg/hour at 150°C and 70 bars absolute (7,000 kPa) with a 6 L/hour liquid recycle. The feed gas then was switched from nitrogen to hydrogen, the pressure slowly was increased to 125.1 bars absolute (12,510 kPa) and, finally, the temperature was increased to the desired reaction temperature. The reaction was commenced by switching the reactor feed from DMCD to 30:70 parts by weight mixture of dimethyl terephthalate and DMCD. Hydrogen was purged from the reactor system at a rate of 8 to 10 L/minute. Carbon monoxide concentrations in the hydrogen purge gas were monitored using a Beckman IR carbon monoxide analyzer. Operating data were recorded when a steady state of operation was achieved, typically 1 to 2 hours from the commencement of the reaction.

The catalysts employed in the examples are described in Table I and contained 1.0 weight percent palladium, as well as a second Group VIII metal, on theta alumina. In Table I, the second metal and its concentration on the catalyst are given, BET SA is the BET surface area of the catalyst in m^2/g , Pore Volume is given in mL/g as determined by nitrogen adsorption according to known procedures [Charles Satterfield, Heterogeneous Catalysis in Industrial Practice, 2nd Ed., McGraw-Hill, Inc., 199, pages 141-143], Pore Diameter is determined by nitrogen adsorption and is given in angstroms, and Pd Disp. is the percent of the palladium which is exposed. The catalysts, all of which are commercially available, were in the form of 3 mm pellets.

TABLE I

<u>Catalyst</u>	<u>Second Metal</u>	<u>BET SA</u>	<u>Pore Volume</u>	<u>Pore Diameter</u>	<u>Dispersion H₂</u>	<u>Dispersion CO</u>
A	Ni(200 ppm)	122	0.64	211	40	37
B	Ru(200 ppm)	122	0.65	212	38	38
C	Pt(200 ppm)	110	0.62	224	12	18
D	Ni(1000 ppm)	118	0.64	216	36	36

EXAMPLES 1-18

Dimethyl terephthalate was hydrogenated to DMCD under 125.1 bars absolute (12,510 kPa) pressure using the catalysts and the procedure described hereinabove.

- 5 The catalysts used in the examples were: Catalyst A - Examples 1-5; Catalyst B - Examples 6-12; Catalyst C - Examples 13-15; and Catalyst D - Examples 16-18. The results obtained are shown in Table II wherein Temp. specifies the temperature in °C used in each example,
- 10 Feed Rate is the rate in g per minute at which a DMT/DMCD mixture having a DMT:DMCD weight ratio of 30:70 was fed to the reactor, DMT in Product is the weight percent of the product which consists of unconverted dimethyl terephthalate, Rate is the g of DMT converted
- 15 per g of catalyst per hour, and CO is the concentration in ppm of carbon monoxide in the hydrogen purge gas.

TABLE II

	<u>Example</u>	<u>Temp.</u>	<u>Feed Rate</u>	<u>DMT in Product</u>	<u>Rate</u>	<u>CO</u>
5	1	200	85.4	0.71	1500	37
	2	160	86.4	2.0	1450	3
	3	150	82.5	6.8	1150	0
10	4	180	98.0	0.71	1720	10
	5	180	125.7	2.6	2070	20
15	6	180	83.6	1.0	1450	3
	7	180	83.2	1.0	1450	13
	8	200	82.3	0.4	1460	24
20	9	180	85.4	0.7	1500	12
	10	180	124.6	2.8	2030	20
25	11	180	86.5	1.6	1470	14
	12	160	81.3	4.1	1390	4
	13	180	83.5	0.3	1490	48
30	14	160	84.2	4.6	1280	27
	15	200	83.5	0.2	1500	—
35	16	177	118	2.0	1970	36
	17	155	116	6.4	1640	5
40	18	165	116	2.6	1910	12

The DMT in Product, Rate and/or CO concentrations reported in Table II were consistently superior than the values which were predicted from results obtained when DMT was hydrogenated substantially as described in the preceding examples using a supported palladium catalyst having the characteristics described herein but without the second Group VIII metal. For example, the rates



observed for Examples 16-18 in which a
palladium/nickel/alumina catalyst was used were 24-45%
greater than the rates which are predicted from DMT
hydrogenations using an analogous palladium/alumina
5 catalyst.

The invention has been described in detail with
particular reference to preferred embodiments thereof,
but it will be understood that variations and
modifications can be effected within the spirit and
10 scope of the invention.



CLAIMS

We claim:

1. Process for the preparation of a dimethyl cyclohexanedicarboxylate which comprises contacting a
5 dimethyl benzenedicarboxylate with hydrogen at a temperature of 140 to 400°C and a pressure of 10 to 200 bars absolute (1,000 to 20,000 kPa) in the presence of a supported catalyst comprising palladium and a second Group VIII metal selected from nickel, platinum,
10 ruthenium or a mixture thereof deposited on an alumina support; wherein
 - (1) palladium comprises 0.1 to 5.0 weight percent of the catalyst;
 - (2) the palladium dispersion is at least 15 percent;
 - 15 (3) at least 90 weight percent of the palladium is located on the alumina at a depth less than 200 microns from the surface of the alumina;
 - (4) the second Group VIII metal selected from nickel, platinum, ruthenium or a mixture thereof comprises
20 0.001 to 1 weight percent of the catalysts; and
 - (5) the crystalline phase of the alumina is alpha, theta, delta, gamma, eta or a mixture thereof.
2. Process according to Claim 1 which comprises
25 contacting a dimethyl benzenedicarboxylate with hydrogen at a temperature of 140 to 400°C and a pressure of 10 to 200 bars absolute (1,000 to 20,000 kPa) in the presence of a supported catalyst comprising palladium and a second Group VIII metal selected from nickel, platinum,
30 ruthenium or a mixture thereof deposited on an alumina support; wherein
 - (1) palladium comprises 0.5 to 2.0 weight percent of the catalyst;
 - (2) the palladium dispersion is at least 30 percent;



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- (3) at least 90 weight percent of the palladium is located on the alumina at a depth less than 100 microns from the surface of the alumina;
- (4) the second Group VIII metal selected from nickel, platinum, ruthenium or a mixture thereof comprises 0.01 to 0.5 weight percent of the catalysts; and
- (5) the crystalline phase of the alumina is alpha, theta, delta or a mixture thereof.
3. Process according to Claim 2 wherein a solution of the dimethyl benzenedicarboxylate in dimethyl cyclohexanedicarboxylate is contacted with hydrogen.
4. Process for the preparation of a dimethyl cyclohexanedicarboxylate which comprises contacting a dimethyl benzenedicarboxylate with hydrogen at a temperature of 140 to 400°C and a pressure of 50 to 170 bars absolute (5,000 to 17,000 kPa) in the presence of a supported catalyst comprising palladium and nickel deposited on an alumina support; wherein
- (1) palladium comprises 0.1 to 5.0 weight percent of the catalyst;
- (2) the palladium dispersion is at least 20 percent;
- (3) at least 90 weight percent of the palladium is located on the alumina at a depth less than 200 microns from the surface of the alumina;
- (4) nickel comprises 0.01 to 0.5 weight percent of the catalysts; and
- (5) the crystalline phase of the alumina is alpha, theta, delta, gamma, eta or a mixture thereof.
5. Process according to Claim 4 which comprises contacting a dimethyl benzenedicarboxylate with hydrogen at a temperature of 140 to 250°C and a pressure of 50 to 170 bars absolute (5,000 to 17,000 kPa) in the presence



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of a supported catalyst comprising palladium and nickel deposited on an alumina support; wherein

- (1) palladium comprises 0.5 to 2.0 weight percent of the catalyst;
- 5 (2) the palladium dispersion is at least 30 percent;
- (3) at least 90 weight percent of the palladium is located on the alumina at a depth less than 100 microns from the surface of the alumina; and
- (4) nickel comprises 0.01 to 0.5 weight percent of the
10 catalysts; and
- (5) the crystalline phase of the alumina is alpha, theta, delta or a mixture thereof.

6. Process according to Claim 5 for the preparation of
15 dimethyl 1,4-cyclohexanedicarboxylate wherein a solution of dimethyl 1,4-benzenedicarboxylate in dimethyl 1,4-cyclohexanedicarboxylate is contacted with hydrogen.

7. Process according to Claim 5 for the preparation of
20 dimethyl 1,3-cyclohexanedicarboxylate wherein a solution of dimethyl 1,3-benzenedicarboxylate in dimethyl 1,3-cyclohexanedicarboxylate is contacted with hydrogen.

8. Process according to Claim 5 for the preparation of
25 dimethyl 1,2-cyclohexanedicarboxylate wherein a solution of dimethyl 1,2-benzenedicarboxylate in dimethyl 1,2-cyclohexanedicarboxylate is contacted with hydrogen.



Low pressure for the hydrogenation of dimethyl benzenedicarboxylates
to the corresponding dimethyl cyclohexanedicarboxylates:

ABSTRACT

Disclosed is a process for the preparation of a
dimethyl cyclohexanedicarboxylate by the hydrogenation
of the corresponding dimethyl benzenedicarboxylate ester
5 in the presence of a class of supported catalysts
comprising palladium and a second Group VIII metal
selected from nickel, platinum, ruthenium or a mixture
thereof deposited on an alumina support which have a
unique combination of characteristics. The use of the
10 catalysts permits the process to be carried out at
significantly lower process pressures.

DATE OF RECEIPT 17 SEP 1998

alumina employed contains 0.5 weight percent palladium deposited on alumina, the crystalline phase of which is a mixture of bayerite and boehmite. The catalyst is used in the form of 3 mm chips and exhibits poor physical strength.

It is apparent that chemical processes which require the use of high pressures such as pressures in excess of 340 bars (34,000 kPa) are inherently expensive due to the increased operating costs and the cost of the apparatus required including the high pressure-rated reactor and the compressors. It has been found, however, that when the hydrogenation of dimethyl terephthalate to dimethyl 1,4-cyclohexanedicarboxylate is carried out at pressures less than 135 bars absolute (13,500 kPa) using the above-described palladium on alumina catalyst, commercially acceptable hydrogenation rates cannot be achieved over an extended period of time. For example, when operating continuously at 125 bars absolute (12,500 kPa) using the above-described catalyst, the process is unstable and the hydrogenation rate typically is not more than approximately 55% of the rates achieved at approximately 410 bars absolute (41,000 kPa) pressure. The reduced hydrogenation rate is due to decreased activity of the palladium catalyst which, we believe, is related to the generation of carbon monoxide during the hydrogenation at lower pressures. It is known that the presence of carbon monoxide in hydrogen gas used in hydrogenation processes is detrimental to such processes. However, the extreme sensitivity of the above-described palladium on alumina catalyst to parts per million (ppm) amounts of carbon monoxide is surprising.

EP-A-0 005 737 discloses a process for the preparation of cycloaliphatic carboxylic acid esters. Moreover, this document in general discloses a process utilizing a supported catalyst comprising palladium and ruthenium. There is no disclosure that at least 90 weight % of the palladium is located on the catalyst at a depth less than 200 microns from the surface of the catalyst. There is further no acknowledgement that the palladium dispersion may be at least 15 %.

The present invention is concerned with a process whereby dimethyl benzenedicarboxylates may be

observed for Examples 16-18 in which a palladium/nickel/alumina catalyst was used were 24-45% greater than the rates which are predicted from DMT hydrogenations using an analogous palladium/alumina catalyst.



- (3) at least 90 weight percent of the palladium is located on the alumina at a depth less than 100 microns from the surface of the alumina;
- (4) the second Group VIII metal selected from nickel, platinum, ruthenium or a mixture thereof comprises 0.01 to 0.5 weight percent of the catalysts; and
- (5) the crystalline phase of the alumina is alpha, theta, delta or a mixture thereof.

3. Process according to Claim 2 wherein a solution of the dimethyl benzenedicarboxylate in dimethyl cyclohexanedicarboxylate is contacted with hydrogen.

4. Process according to claim 1 wherein the catalyst comprises palladium and nickel deposited on an alumina support; wherein

- (1) palladium comprises 0.1 to 5.0 weight percent of the catalyst;
- (2) the palladium dispersion is at least 20 percent;
- (3) at least 90 weight percent of the palladium is located on the alumina at a depth less than 200 microns from the surface of the alumina;
- (4) nickel comprises 0.01 to 0.5 weight percent of the catalysts; and
- (5) the crystalline phase of the alumina is alpha, theta, delta, gamma, eta or a mixture thereof.

5. Process according to Claim 4 which comprises contacting a dimethyl benzenedicarboxylate with hydrogen at a temperature of 140 to 250°C and a pressure of 50 to 170 bars absolute (5,000 to 17,000 kPa) in the presence of a supported catalyst comprising palladium and nickel deposited on an alumina support; wherein

- (1) palladium comprises 0.5 to 2.0 weight percent of the catalyst;
- (2) the palladium dispersion is at least 30 percent;
- (3) at least 90 weight percent of the palladium is located on the alumina at a depth less than 100 microns from the surface of the alumina; and



- (4) nickel comprises 0.01 to 0.5 weight percent of the catalysts; and
- (5) the crystalline phase of the alumina is alpha, theta, delta or a mixture thereof.

6. Process according to Claim 5 for the preparation of dimethyl 1,4-cyclohexanedicarboxylate wherein a solution of dimethyl 1,4-benzenedicarboxylate in dimethyl 1,4-cyclohexanedicarboxylate is contacted with hydrogen.

7. Process according to Claim 5 for the preparation of dimethyl 1,3-cyclohexanedicarboxylate wherein a solution of dimethyl 1,3-benzenedicarboxylate in dimethyl 1,3-cyclohexanedicarboxylate is contacted with hydrogen.

8. Process according to Claim 5 for the preparation of dimethyl 1,2-cyclohexanedicarboxylate wherein a solution of dimethyl 1,2-benzenedicarboxylate in dimethyl 1,2-cyclohexanedicarboxylate is contacted with hydrogen.