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(54) Title: PROCESS TO PRODUCE ADIPIC ACID AND DIESTERS THEREOF IN A CARBONYLATION PROCESS USING PALLADIUM BIDENTATE BIPHOSPHATE LIGANDS

(57) Abstract: The invention relates to a carbonylation process for the preparation of a compound of formula (I) $\text{XOOC}-(\text{CH}_2)_4-\text{COOY}$ (I) wherein X and Y can independently represent H and/or alkyl, said carbonylation process comprising reacting: (a) a composition comprising at least one isomeric methyl pentenoate; (b) a source of Pd; (c) a bidentate di-phosphine of formula II, $\text{R}^1\text{R}^2\text{P}-\text{R}^3-\text{R}-\text{R}^4-\text{PR}^5\text{R}^6$ (II) wherein P represents a phosphorus atom; R^1 , R^2 , R^5 and R^6 can independently represent the same or different optionally substituted organic groups containing a tertiary carbon atom through which the group is linked to the phosphorus atom; R^3 and R^4 independently represent optionally substituted lower alkylene groups and R represents an optionally substituted aromatic group; (d) a source of anions derived from an acid with a $\text{pK}_a < 3$; (e) carbon monoxide; and (f) an OH group comprising compound, under conditions wherein (I) is produced, characterized in that the least one isomeric methyl pentenoate comprises methyl 2-pentenoate. The process advantageously has a high conversion rate and may be used without the need to separate methyl 2-pentenoate from mixtures also containing methyl 3- and/or 4 pentenoate in order to isomerise the methyl 2-pentenoate. The process is suitable for the production of dimethyl adipate, adipic acid and hexamethylene diamine and products derived thereof such as nylon 6,6 from renewable sources such as plant waste, sewage waste *etceteras* instead of using fossil sources.



**PROCESS TO PRODUCE ADIPIC ACID AND DIESTERS THEREOF IN A CARBONYLATION
PROCESS USING PALLADIUM BIDENTATE BIPHOSPHATE LIGANDS**

Field of the invention

The present invention relates to a carbonylation process for the production of adipic acid and diester thereof and their use. The invention also relates to the production of polymers based on adipic acid.

Background of the invention

Adipic acid (1,6-hexanedioic acid) is an important precursor for *inter alia* the production of polyamides such as Nylon 6,6 or StanylTM. Further, esters of adipic acid may be used in plasticisers, lubricants, solvent and in a variety of polyurethane resins. Other uses of adipic acid are as food acidulants, applications in adhesives, insecticides, tanning and dyeing.

The most important process to produce adipic acid is based on oil and starts from benzene. In this process benzene is hydrogenated to cyclohexane. Cyclohexane is then oxidised using HNO₃ as oxidant to adipic acid. A disadvantage of this process is that it is based on fossil derived oil. Another disadvantage of this process is the poor selectivity which leads to the formation of a mixture of diacids, which poses purification problems. A third disadvantage is the evolution of NO_x during the oxidations step, which either is vented to the air, which is highly undesirable as it is a greenhouse gas, or its catalytically destroyed, which is an expensive process. New processes for the production of adipic acid have been developed based on butadiene. In one of these processes, butadiene is converted tot methyl 3-pentenoate. The next step is isomerisation of methyl 3-pentenoate to methyl 4-pentenoate which can be converted to dimethyladipate. However, the separation of the 4-pentenoate and the 3-pentenoate esters by distillation is problematic due to the small difference in boiling point. Sometimes the isomerisation and methoxycarbonylation are performed in a single step. Finally, dimethyl adipate is hydrolyzed to adipic acid. A disadvantage of the butadiene –based processes is the high cost of butadiene. A second disadvantage is the low rate of the methoxycarbonylation of butadiene. Because of this, high concentrations of palladium catalyst are needed, which leads to rapid catalyst deactivation.

In WO2001068583 is described the use of a bidentate di-phosphine of formula (I) for the carbonylation of methyl 3-pentenoate to prepare diesters of adipic acid in a carbonylation process comprising reacting:

- (a) a composition comprising methyl 3-pentenoate;
- (b) a source of Pd;

(c) a bidentate di-phosphine of formula I,



wherein P represents a phosphorus atom; R^1 , R^2 , R^5 and R^6 can independently represent the same or different optionally substituted organic groups containing a tertiary carbon atom through which the group is linked to the phosphorus atom; R^3 and R^4 independently represent optionally substituted lower alkylene groups and R represents an optionally substituted aromatic group;

(d) a source of anions derived from an acid with a $pK_a < 3$;

(e) carbonmonoxide; and

(f) an OH group comprising compound.

WO2001068583 is silent on the use of the ligand of formula (I) as part of a catalyst for the conversion of methyl 2-pentenoate.

A carbonylation process as described above involving the bidentate di-phosphine of formula (I) is known from Jiménez-Rodrigues et al. (Inorg. Chem. Comm. (2005), vol. 8, p. 878), who describe its use in the palladium-catalysed carbonylation of methyl 3-pentenoate to form dimethyl adipate. They also describe the methoxycarbonylation of the *free* 2-pentenoic acid which results in the formation of dimethyl adipate. However, Jiménez-Rodrigues et al. are silent on the use of *methyl* 2-pentenoate in the carbonylation reaction.

In WO/0248094 a process is described wherein the bidentate di-phosphine of formula (I) is used to convert methyl-3-pentenoic acid to adipate dimethylester.

In WO2009010782 is described that the bidentate di-phosphine according to formula (I) can be used for the carbonylation of alkyl pentenoates such as methyl 3-pentenoate and pentene acids such as 2- and 3-pentenoic acid. However, WO2009010782 is silent on the conversion of methyl 2-pentenoates.

In WO2006125801 is described the use of the bidentate di-phosphine of formula (I) for the carbonylation of 2-, 3-, and 4-pentenoic acid, but not of methyl pentenoates.

It is highly desirable to produce polymers such as nylon-6,6 from renewable resources. Such a process reduces the total amount of CO₂ emitted for its production and thus helps to mitigate against global warming. In addition, it helps to slow down the depletion of fossil resources. Levulinic acid may be produced from agricultural waste products or waste from the paper industry or municipal waste and therefore constitutes a renewable source of a C-5 fragment. The hydrogenation of levulinic acid has been described and produces valerolactone in high yield. A number of patents exist describing the reaction of valerolactone with methanol, either in the liquid phase or in the gas phase to deliver a mixture of methyl 2-pentenoate, methyl 3-pentenoate and methyl 4-pentenoate. As described above, the conversion of methyl 3-pentenoate and methyl 4-pentenoate into dimethyl adipate has already been reported. However, the presence of methyl 2-pentenoate in these mixtures obtained from the conversion of valerolactone constitutes a serious problem. In this compound the double bond is in the α - position and this is in conjugation with the ester group which causes reactivity of this bond, which

is totally different from the double bonds in methyl 3- or 4-pentenoate. It is well known to someone skilled in the art that nucleophiles can add very easily to this type of double bond in a reaction called a 1,4-addition. The 1,4-addition of phosphine ligands to such an olefin leads to the formation of stable phosphonium salts. This is a well-documented reaction which has been described in among others: C. Gimbert, A. Vallribera, J. A. Gladysz, M. Jurisch, *Tetrahedron Letters* 51 (2010) 4662–4665; and in M. Hernandez and P. Kalck, *Journal of Molecular Catalysis A: Chemical* 116 (1997) 131-146. It is also known that this reaction is catalysed by acids. This process depletes the ligand from the solution and since the catalyst, which is a complex between palladium and the phosphorus ligand(s) is only stable in the presence of excess ligand, this process leads to the stripping off of the ligand from the catalyst, leaving the metal unligated. It is well-known to someone skilled in the art that in the case of palladium this leads to formation of palladium black or worse, plating of palladium on the walls of the reactor. In both cases the reaction stops or becomes extremely slow. A second possible deactivation mechanism of the catalyst in the presence of methyl 2-pentenoate is the formation of a highly stable palladium alkyl complex. Formation of the palladium alkyl complex is a necessary step in the isomerising methoxycarbonylation of pentenoate esters. Normally speaking these palladium alkyl complexes are unstable and will rapidly react either in the isomerisation towards the desired 4-pentenoate or by insertion of CO, once the terminal palladium complex has been formed. However, in the case of the formation of the palladium alkyl complex based on methyl 2-pentenoate a stable 5-ring structure can be formed in which the carbonyl of the ester group coordinates to palladium. This type of reaction is known from: J. M. Brown and K. K. Hii, *Angew. Chem. Int. Ed. Engl.*, 1996, 35, 657-659. Formation of such a stable species thus will retard the necessary isomerisation reaction. Brown and Hii have shown that basic conditions are necessary to prevent the formation of such a species. Unfortunately, the palladium-catalysed carbonylation of pentenoic esters demands acidic conditions. A third problem is that of all the different isomers of methyl pentenoate methyl 2-pentenoate is the most stable one as the double bond is in conjugation with the ester group. Thus it will be very hard to isomerise the 2-pentenoate ester to the 4-pentenoate ester since the latter is higher in energy.

The boiling points of the isomeric methyl pentenoates are very close, making it very difficult to separate methyl 2-pentenoate from mixtures containing methyl 3- and/or 4-pentenoate using distillation.

Thus it is not surprising that the alkoxycarbonylation of methyl 2-pentenoate or of a mixture of alkyl 2-, 3- and 4-pentenoate has not been described. As a result, the skilled person would stay away from using methyl-2-pentenoic acid in a carbonylation process to produce adipic acid diester.

In WO02/46143 is described the carbonylation of n-pentenoic acid derivatives such as methyl pentenoate. It is described that the n-pentenoic acid derivatives can be all isomers such as 2, 3, and 4 isomers. Although WO02/46143 refers to the fact that the methyl pentenoate may

be a mixture of the different isomers, WO02/46143 advises that the mixtures contain preferably at least 80% methyl 3-pentenoate. However, the actual amounts of methyl 2-pentenoate in such mixtures are not disclosed. Moreover, in the Examples of WO02/46143 only 3-pentenitril and methyl 3-pentenoate are used in the carbonylation reaction.

5 The inventor has surprisingly realized that adipic alkyl diesters can be efficiently produced using a composition comprising alkyl 2-pentenoate. It is an aim of the invention to increase the conversion velocity.

10 Detailed description of the invention

In a first aspect, the invention relates to a carbonylation process for the preparation of a compound of formula I

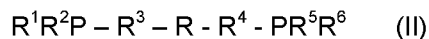


wherein X and Y can independently represent H or alkyl, said carbonylation process comprising
15 reacting:

(a) a composition comprising at least one isomeric methyl pentenoate;

(b) a source of Pd;

(c) a bidentate di-phosphine of formula II,



20 wherein P represents a phosphorus atom; R^1 , R^2 , R^5 and R^6 can independently represent the same or different optionally substituted organic groups containing a tertiary carbon atom through which the group is linked to the phosphorus atom; R^3 and R^4 independently represent optionally substituted lower alkylene groups and R represents an optionally substituted aromatic group;;

(d) a source of anions derived from an acid with a $\text{pK}_a < 3$;

25 (e) carbon monoxide; and

(f) an OH group comprising compound,

under conditions wherein (I) is produced, characterized in that the least one isomeric methyl pentenoate comprises methyl 2-pentenoate,.

30 Preferably, the lower alkylene groups which R^3 and/or R^4 represent are non-substituted. R^3 and R^4 may independently represent $-\text{CH}_2-$ or $-\text{C}_2\text{H}_4-$. In a preferred embodiment R^1 , R^2 , R^5 , and R^6 are tert-butyl, R^3 and R^4 are methylene, and R is ortho-phenylene.

The lower alkyl group preferably has 4 C atoms or less, more preferably 3 C atoms or less, even more preferably 2 C atoms or less, most preferably the lower alkylgroup is methyl.

In one embodiment the alkanoic acid ester of formula II is adipate monoester.

35 In another, highly preferred embodiment the alkanoic acid ester of formula II is adipate dimethylester.

The methyl 2-pentenoate may be *cis*- or *trans*-methyl 2-pentenoate or a mixture thereof.

The inventor has found that the process of the first aspect of the invention may advantageously have a high conversion rate and may be used without the need to separate methyl 2-pentenoate from mixtures also containing methyl 3- and/or 4-pentenoate in order to isomerise the methyl 2-pentenoate. The process is beneficial for the production of adipic dimethyl ester from renewable sources such as plant waste, sewage waste *etceteras* instead of using fossil sources.

The process of the invention is optionally performed in the presence of an additional solvent. In practice, diesters of adipic acid or the heavies that build up during the recycle of the catalyst may function as a solvent. The additional solvent is preferably an aprotic solvent. Suitable solvents include ketones, such as for example methylbutylketone; ethers, such as for example anisole (methyl phenyl ether), 2,5,8-trioxanonane (diglyme), diethylether, tetrahydrofuran, 2-methyl-tetrahydrofuran, diphenylether, diisopropylether and the dimethylether of di-ethyleneglycol; esters, such as for example ethyl acetate, methyl acetate, dimethyl adipate and butyrolactone; amides, such as for example dimethylacetamide and N-methylpyrrolidone; and sulfoxides and sulphones, such as for example dimethylsulphoxide, di-isopropylsulphone, sulfolane (tetrahydrothiophene-2,2-dioxide) 2-methylsulfolane and 2-methyl-4-ethylsulfolane. Very suitable are aprotic solvents having a dielectric constant that is below a value of 50, more preferably in the range of 3 to 8, at 298.15 K and 1 bar. If the hydroxyl group containing compound is an alkanol, a further preferred aprotic solvent is the ester carbonylation product of the compound of formula I, carbon monoxide and the alkanol.

Suitable sources of Pd in the process of the invention include its salts, such as for example the salts of palladium and halide acids, nitric acid, sulphuric acid or sulphonic acids; palladium complexes, e. g. with carbon monoxide, dienes, such as dibenzylideneacetone (dba) or acetylacetonate, palladium nanoparticles or palladium combined with a solid carrier material such as carbon, silica or an ion exchanger. Preferably, a salt of palladium and a carboxylic acid is used, suitably a carboxylic acid with up to 12 carbon atoms, such as salts of acetic acid, propionic acid, butanoic acid or 2-ethyl-hexanoic acid, or salts of substituted carboxylic acids such as trichloroacetic acid and trifluoroacetic acid. A very suitable source is palladium (II) acetate.

In a preferred embodiment the source of Pd is selected from the group consisting of palladium halide, palladium carboxylate and Pd₂(dba)₃.

The molar ratio of bidentate phosphine of formula 1 to palladium is preferably from 1-20, more preferably from 1-10, even more preferably from 2-6.

Suitable reaction temperatures are in the range of 20-160°C, more preferably in the range of 50-120°C.

The pressure in the process of the invention is preferably between 5 and 100 bar, more preferably between 10 and 50 bar.

Esters are obtained if the OH group containing compound is an alkanol. More preferably the OH group containing compound is an alcohol, most preferably methanol.

In an embodiment the OH group comprising compound is water.

Throughout this specification "adipic acid dimethylester" and "dimethyl adipate" are
5 understood to have the same meaning.

The source of anions derived from acid having a pKa below 3.0 (measured in aqueous solution at 18 °C) is preferably a non-coordinating anion. Hereby is meant that little or no covalent interaction takes place between the palladium and the anion.

Examples of suitable anions include anions of phosphoric acid, sulphuric acid, sulphonic
10 acids and halogenated carboxylic acids such as trifluoroacetic acid.

Sulphonic acids are particularly preferred, such as for example trifluoromethanesulphonic acid, p-toluenesulphonic acid and 2,4,6-trimethylbenzene sulphonic acid, 2-hydroxypropane-2-sulphonic acid, tert-butyl sulphonic acid, methyl sulphonic acid. The acid can also be an ion exchange resin containing sulphonic acid groups.

15 Even more preferred are methylsulphonic acid, *tert*-butyl sulphonic acid and 2,4,6-trimethylbenzenesulphonic acid.

The molar ratio of the source of anions and palladium is preferably between 1 : 1 and 100 : 1 and more preferably between 1 : 1 and 10 : 1.

In the present context, the dielectric constant for a given solvent is used in its normal
20 meaning of representing the ratio of the capacity of a condenser with that substance as dielectric to the capacity of the same condenser with a vacuum for dielectric. Values for the dielectric constants of common organic liquids can be found in general reference books, such as the Handbook of Chemistry and Physics, 76th edition, edited by David R. Lide et. al, and published by CRC press
25 in 1995, and are usually quoted for a temperature of about 20 or 25 °C, i.e. about 293.15 or 298.15 K, and atmospheric pressure, i.e. about 1 bar, or can readily be converted to that temperature and pressure using the conversion factors quoted. If no literature data for a particular compound is available, the dielectric constant may be readily measured using established physico-chemical methods.

30 For example, the dielectric constant of anisole is 4.3 (at 294.2 K), of diethyl ether is 4.3 (at 293.2 K), of sulfolane is 43.4 (at 303.2 K), of methylpentanoate is 5.0 (at 293.2 K), of diphenylether is 3.7 (at 283.2 K), of dimethyladipate is 6.8 (at 293.2 K), of tetrahydrofuran is 7.5 (at 295.2 K), of methylnonanoate is 3.9 (at 293.2 K).

The amount of methyl 2-pentenoate in the composition is preferably ≥ 2 wt%, more
35 preferably between 5-85 wt%, 6-80 wt%, even more preferably between 7-70 wt%, 8-60 wt%, even more preferably between 9-50 wt%, 10-40 wt%, even more preferably between 11-30 wt%, 12-20wt%.

In a preferred embodiment the at least one isomeric methyl pentenoate is a mixture comprising *cis*- and/or *trans*-methyl 2-pentenoate and *cis*- and/or *trans*- methyl 3-pentenoate and/or methyl-4-pentenoate. Said mixture may for example comprise methyl 2-pentenoate and methyl 3-pentenoate, methyl 2-pentenoate and methyl 4-pentenoate, or methyl 2-pentenoate, methyl 3-pentenoate, and methyl 4-pentenoate.

The composition comprising at least one isomeric methyl pentenoate may comprise other components, such as free pentenoic acids (2-pentenoic acid, 3-pentenoic acid, and/or 4-pentenoic acid). The total amount of said pentenoic acids is preferably less than 10 % wt. The composition comprising at least one isomeric methyl pentenoate may also comprise valerolactone.

The composition comprising at least one isomeric methyl pentenoate may also comprise water, preferably between 0.1 and 3% wt. A small amount of water may be advantageous as it may accelerate the conversion rate (TOF, h⁻¹). Preferably the amount of water in the composition comprising at least one isomeric methyl pentenoate is between 0.13 and 3% wt, more preferably between 0.19 and 3%, between 0.19 and 2.55% wt, even more preferably between 0.24 and 2.55% wt, even more preferably between 0.51 and 2.55 % wt.

Carbon monoxide partial pressures in the range of 1-65 bar are preferred. In the process according to the present invention, the carbon monoxide can be used in its pure form or diluted with an inert gas such as nitrogen, carbon dioxide or noble gases such as argon. Small amounts of hydrogen can also be present. In general, the presence of more than 5% hydrogen is undesirable, since this can cause hydroformylation or even hydrogenation of the pentenoate esters.

The amount of palladium used in the process according to the first aspect of the invention is the result of careful optimisation in an iterative process known to someone skilled in the art. Whereas high palladium concentrations lead to very fast reactions, they may also result in the formation of palladium black. This latter deactivation process is ameliorated by the presence of ligands and the pentenoate esters. The palladium black formation is also accelerated by high temperatures. In general a range of 10⁻⁷ to 10⁻¹ gram atom per mole of pentenoate esters will be the starting point of this optimisation. More likely, the palladium amount will be in the range of 10⁻⁵ to 10⁻² gat per mole of pentenoate ester.

In a second aspect the invention provides a process to produce adipic acid dimethyl ester, said process comprising:

- (a) converting valerolactone into a mixture of methylpentenoates comprising ≥ 5 % wt methyl 2-pentenoate by treatment with methanol, in the presence of an acidic or basic catalyst in the gas phase or in the liquid phase; and
- (b) converting the mixture of methyl pentenoates produced in step (a) to adipic acid dimethylester in a carbonylation process according to the first aspect of the invention wherein the OH group comprising compound is methanol.

The inventor has surprisingly found that the process of the second aspect of the invention may be advantageously carried out without an additional step after step (a) and before step (b), such as a purification or separation step to remove or reduce the amount of methyl-2-pentenoic acid.

5 The conversion of valerolactone to a mixture of methyl pentenoates in step (a) can be done either in the liquid phase or in the gas phase to deliver a mixture of methyl 2-pentenoate, methyl 3-pentenoate and methyl 4-pentenoate. Such processes are described in WO 2005058793, WO 2004007421, and US 4740613.

10 In an embodiment valerolacton is prepared by converting levulinic acid to valerolactone in a hydrogenation reaction. Such processes are described in L. E. Manzer, *Appl. Catal. A*, 2004, **272**, 249–256; J. P. Lange, J. Z. Vestering and R. J. Haan, *Chem. Commun.*, 2007, 3488–3490; R. A. Bourne, J.G. Stevens, J.Ke and M. Poliakoff, *Chem. Commun.*, 2007, 4632–4634; H. S. Broadbent, G. C. Campbell, W. J. Bartley and J. H. Johnson, *J. Org. Chem.*, 1959, **24**, 1847–1854; R. V. Christian, H. D. Brown and R. M. Hixon, *J. Am. Chem. Soc.*, 1947, **69**, 1961–1963.; L. P. Kyrides and J. K. Craver, *US Patent*, 2368366, 1945; H. A. Schuette and R. W. Thomas, *J. Am. Chem. Soc.*, 1930, **52**, 3010–3012.

15 In another embodiment levulinic acid is prepared by converting a C6 carbohydrate to levulinic acid in an acid-catalysed reaction. Such processes are for example described in L. J. Carlson, *US Patent*, 3065263, 1962; B. Girisuta, L. P. B. M. Janssen and H. J. Heeres, *Chem. Eng. Res.Des.*, 2006, **84**, 339–349; B. F. M. Kuster and H. S. Vanderbaan, *Carbohydr. Res.*, 1977, **54**, 165–176; S. W. Fitzpatrick, WO8910362, 1989, to Biofine Incorporated; S. W. Fitzpatrick, WO9640609 1996, to Biofine Incorporated. Examples of C6 carbohydrates are glucose, fructose, mannose en galactose. Preferred raw material for the C6 carbohydrates is lignocellulosic material containing carbohydrate based polymers composed partly or entirely from C6 sugars such as lignocellulose, cellulose, starch and hemicellulose. The C6 carbohydrate may
25 comprise other components, such as plant waste, sewage etc.

The process to produce adipic acid according to the second aspect of the invention advantageously allows the use of renewable sources such as plant waste, waste from paper production, sewage waste *etceteras* instead of using fossil sources.

30 In a preferred embodiment, the process according to the second aspect of the invention includes isolating dimethyl adipate, e.g. by distillation. Unconverted methyl pentenoates and/or catalyst containing distillation residue and which may still contain some dimethyl adipate may be recycled back into the reactor.

35 In an embodiment DMA is hydrolyzed to adipic acid in a hydrolysis reaction. The hydrolysis of DMA to adipic acid is well known to the person skilled in the art. The hydrolysis is preferably catalysed by an acidic catalyst.

In another embodiment adipate is converted to ammonium adipate by treatment with ammonia.

In another embodiment ammonium adipate is converted to adiponitril in a dehydration reaction.

In another embodiment adiponitril is converted to hexamethylenediamine in a reduction reaction. The conversion of adipate to ammonium adipate, from ammonium adipate to adiponitril and from adiponitril to hexamethylene diamine is known to persons skilled in the art and is for example described by Fernelius *et al.* (Journal of Chemical Education, 1979, vol. 56, p. 654-656).

The following examples are for illustrative purposes only and are not to be construed as limiting the invention.

EXAMPLES

Examples 1-3 Preparation of a mixture of methyl pentenoates

The catalyst (Grace-Davison/Davicat SIAL 3501, 21.2 g) was loaded into a tubular gas phase reactor at atmospheric pressure and then heated to 255°C. The reaction temperature was monitored inside the reactor with a thermocouple. Prior to the introduction of the feed, the desired reaction temperature and pressure were achieved under flowing nitrogen. Gas flow to the reactor was controlled using Brooks mass flow controllers. Upon reaching the desired conditions, a solution of γ -valerolactone in MeOH (1:1 in weight) was prepared, preheated to 190°C and fed to the packed-bed tubular reactor using a HPLC pump. The liquid effluent was collected for quantitative analysis in a separator at ambient temperature and analyzed by GC. The LHSV w.r.t. valerolactone was 0.49. Samples from three different runs were distilled. The composition of the main fraction from these three runs is listed below in Table 1. In all mixtures more than 5 mol% of methyl 2-pentenoate was present.

Table 1. Mass percentages methyl pentenoates in mixtures obtained from the gasphase reaction between valerolactone and methanol

Example	MeOH m/m %	c-M2P m/m %	M4P m/m %	tr-M3P m/m %	c-M3P m/m %	tr-M2P m/m %	Valero- Lactone m/m %	Water m/m %	Total m/m %
1	1.1	2.2	25.0	44.6	16.3	8.7	1.1	1.1	100
2	0.0	0.8	18.3	48.3	17.5	11.7	0.8	0.8	98
3	0.0	1.6	12.9	48.4	17.7	14.5	1.6	1.6	98

Examples 4- Methoxycarbonylation of methyl pentenoates

A solution of α,α' -Bis(di-tert-butylphosphino)-o-xylene (20 μ mol, from Strem Chemicals, Inc., 15, rue de l'Atome, Z.I., 67800 BISCHHEIM, France); 5 eq. in 5 mL methanol), was added to Pd precursor (4 μ mol Pd(OAc)₂). Methanesulfonic acid (MSA, 4 μ l, 40 μ mol, 10 eq.) was added to the catalyst solution upon which the color changed from yellow to orange. Substrate (either methyl 2-pentenoate, methyl 3-pentenoate, or a mixture of methyl 2-pentenoate, methyl 3-pentenoate and methyl 4-pentenoate as obtained in Examples 1-3 or pre-mixed in a 1:1:1 ratio)

was added and the mixture was transferred into a glass insert of an Endeavour (set-up of 8 small autoclaves fitted with an overhead stirrer). The reactors were purged 5 times with N₂ and thereafter 10 times with 20 bar of CO. The reactors were pressurized to 20 bar and heated to the indicated reaction temperature. The reaction vessels were cooled down to room temperature after 1 h and the pressure was released. Conversion to dimethyl adipate and selectivities were determined by means of GC analysis (Table 2).

(M2P = methyl 2-pentenoate; M3P = methyl 3-pentenoate; M4P = methyl 4-pentenoate TOF= turnover frequency = Moles of product obtained per mol of catalyst per hour). Mixtures of M2P, M3P and M4P were obtained in a gas phase reaction by reaction between valerolactone and methanol, as described above)

Table 2. Methoxycarbonylation of methyl pentenoates

	Example	Substrate	Temp (°C)	TOF (h ⁻¹)	Selectivity to dimethyl adipate (%)
Examples of the process according to the invention	4	M2P	50	105	100
	5	M2P	75	289	100
	6	M2P	100	417	97
	7	Mixture from Example 1	75	362	100
	8	Mixture from Example 2	75	335	100
	9	Mixture from Example 3	75	482	97
	10	M2P, M3P, M4P (1:1:1)	75	309	100
	11	M2P, M3P, M4P (1:1:1)	100	342	97
Comparative examples	12	M3P	50	141	100
	13	M3P	75	281	100
	14	M3P	100	332	98

Table 2 shows that methyl 2-pentenoate may be converted at practically the same rate and with the same selectivities as methyl 3-pentenoate at 50, 75 and 100 °C. In addition, the mixture containing methyl 2-pentenoate, methyl 3-pentenoate and methyl 4-pentenoate was also converted to methyl adipate with the same rate and selectivity as methyl 3-pentenoate. This experiment shows that it is possible to use the mixture of methyl pentenoates obtained by converting valerolactone in the methoxycarbonylation reaction to dimethyl adipate and that the presence of methyl 2-pentenoate in this mixture has no adverse effects.

Examples 13-19 Effect of added water

A solution of α,α' -Bis(di-tert-butylphosphino)-o-xylene (40 μ mol, 5 eq.) in 4 mL methanol was added to the Pd precursor (8 μ mol Pd(OAc)₂). Methanesulfonic acid (8 μ l, 80 μ mol, 10 eq.) was added to the catalyst solution upon which a color change was visible from yellow to orange. Methyl pentenoate (6.4 mmol) and water were added and the mixture was transferred into a glass Endeavor insert. The reactors were purged 5 times with N₂ and thereafter 10 times with 20 bar of CO. The reactors were pressurized to 20 bar with CO and heated to the indicated reaction

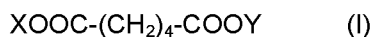
temperature. The reaction vessels were cooled down to r.t. after 1 h and the pressure was released. Conversions and selectivities were determined by means of GC analysis. The exact amounts of water were determined by Karl Fisher titration. Results are shown in Table 3.

5 **Table 3. Effect of water**

Example	Wt% water	C (%)	Sel to DMA(%)	TOF (h ⁻¹)
13	0.13	75	95	562
14	0.19	78	96	591
15	0.24	79	97	598
16	0.51	78	94	611
17	1.185	75	96	591
18	1.7	70	91	547
19	2.55	68	91	534

CLAIMS

1. Carbonylation process for the preparation of a compound of formula I



wherein X and Y can independently represent H and/or alkyl, said carbonylation process comprising reacting:

(a) a composition comprising at least one isomeric methyl pentenoate;

(b) a source of Pd;

(c) a bidentate di-phosphine of formula II,



wherein P represents a phosphorus atom; R^1 , R^2 , R^5 and R^6 can independently represent the same or different optionally substituted organic groups containing a tertiary carbon atom through which the group is linked to the phosphorus atom; R^3 and R^4 independently represent optionally substituted lower alkylene groups and R represents an optionally substituted aromatic group;

(d) a source of anions derived from an acid with a $\text{pK}_a < 3$;

(e) carbon monoxide; and

(f) an OH group comprising compound,

under conditions wherein (I) is produced, characterized in that the least one isomeric methyl pentenoate comprises methyl 2-pentenoate.

2. Process according to claim 1 wherein the amount of methyl 2-pentenoate in the composition is ≥ 2 wt%.

3. Process according to claim 1 or 2 wherein the amount of methyl 2-pentenoate in the composition is between 5-85 wt%.

4. Process according to any one of claims 1-3 wherein R^1 , R^2 , R^5 , and R^6 are *tert*-butyl, wherein R^3 and R^4 are methylene, and wherein R is *ortho*-phenylene.

5. Process according to any one of claims 1-4 wherein the process is carried out in the presence of an aprotic solvent.

6. Process according to any one of claims 1-5 wherein the source of Pd is a is selected from the group consisting of palladium halide, palladium carboxylate and $\text{Pd}_2(\text{dba})_3$.

7. Process according to any one of claims 1-6 wherein the temperature is between 20-160°C.

8. Process according to any one of claims 1-7 wherein the pressure is between 5 and 100 bar.

9. Process according to any one of claims 1-8 wherein the OH comprising compound is methanol.

10. Process according to any one of claims 1-9 wherein the at least one isomeric methyl pentenoate is a mixture comprising *cis*- and/or *trans*-methyl 2-pentenoate and *cis*- and/or *trans*- methyl 3-pentenoate and/or methyl-4-pentenoate.
- 5 11. Process according to any one of claims 1-10 wherein the composition comprising at least one isomeric methylpentenoate comprises water, preferably between 0.1 and 3% w/w.
12. Process to produce adipic acid dimethyl ester, said process comprising:
(a) converting valerolactone into a mixture of methylpentenoates comprising ≥ 5 % wt methyl 2-pentenoate with methanol, in the presence of an acidic or basic catalyst in
10 the gas phase or in the liquid phase; and
(b) converting the methyl pentenoate mixture produced in step (a) to adipic acid dimethyl ester in a carbonylation process according to any one of claims 1-11 wherein the OH group comprising compound is methanol.
13. Process according to claim 12 wherein valerolacton is prepared by converting
15 levulinic acid to valerolactone in a hydrogenation reaction.
14. Process according to claim 13 wherein levulinic acid is prepared by converting a C6 carbohydrate to levulinic acid in an acid-catalysed reaction.
15. Process according to any one of claims 12-14 wherein adipic acid dimethyl ester is converted to adipic acid in a hydrolysis reaction.
- 20 16. Process according to claim 15 wherein adipate is converted to ammonium adipate by treatment with ammonia.
17. Process according to claim 16 wherein ammonium adipate is converted to adiponitril in a dehydration reaction.
- 25 18. Process according to claim 17 wherein adiponitril is converted to hexamethylenediamine in a reduction reaction.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/055769

A. CLASSIFICATION OF SUBJECT MATTER

INV. C07C67/38 C07C67/03 C07C69/44 C07C69/533 C07C51/09
C07C55/14 C07C209/48 C07C211/12 C07C253/00 C07D307/33

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C07C C07D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data, CHEM ABS Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/055769

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