

**(METHYLCYCLOHEXYL)TOLUENE ISOMER MIXTURES, THEIR
PRODUCTION AND THEIR USE IN THE MANUFACTURE OF PLASTICIZERS**

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PRIORITY

[0001] This application claims the benefit of and priority to Provisional Application No. 61/781,137, filed March 14, 2013.

FIELD

[0002] The disclosure relates to (methylcyclohexyl)toluene isomer mixtures, their production and their use as precursors in the manufacture of plasticizers.

BACKGROUND

[0003] Plasticizers are incorporated into a resin (usually a plastic or elastomer) to increase the flexibility, workability, or distensibility of the resin. The largest use of plasticizers is in the production of "plasticized" or flexible polyvinyl chloride (PVC) products. Typical uses of plasticized PVC include films, sheets, tubing, coated fabrics, wire and cable insulation and jacketing, toys, flooring materials such as vinyl sheet flooring or vinyl floor tiles, adhesives, sealants, inks, and medical products such as blood bags and tubing, and the like.

[0004] Other polymer systems that use small amounts of plasticizers include polyvinyl butyral, acrylic polymers, nylon, polyolefins, polyurethanes, and certain fluoroplastics. Plasticizers can also be used with rubber (although often these materials fall under the definition of extenders for rubber rather than plasticizers). A listing of the major plasticizers and their compatibilities with different polymer systems is provided in "Plasticizers," A. D. Godwin, in Applied Polymer Science 21st Century, edited by C. D. Craver and C. E. Carraher, Elsevier (2000); pp. 157-175.

[0005] The most important chemical class of plasticizers is phthalic acid esters, which accounted for about 84% worldwide of PVC plasticizer usage in 2009. However, there is an effort to decrease the use of phthalate esters as plasticizers in PVC, particularly in end uses where the product contacts food, such as bottle cap liners and sealants, medical and food films, or for medical examination gloves, blood bags, and IV delivery systems, flexible tubing, or for toys, and the like. As a result, there is a need for non-phthalate, mono- or diester plasticizers, particularly oxo-ester plasticizers, that can be made from low cost feeds and employ few manufacturing steps in order to have comparable economics with their phthalate counterparts. For these and most other uses of plasticized polymer systems,

however, a successful substitute for phthalate esters has not yet been found.

[0006] One such suggested substitute for phthalates are esters based on cyclohexanoic acid. In the late 1990's and early 2000's, various compositions based on cyclohexanoate, cyclohexanedioates, and cyclohexanepolyoate esters were said to be useful for a range of goods from semi-rigid to highly flexible materials. See, for instance, WO 99/32427, WO 2004/046078, WO 2003/029339, U.S. Patent Publication No. 2006-0247461, and U.S. Patent No. 7,297,738.

[0007] Other suggested substitutes include esters based on benzoic acid (see, for instance, U.S. Patent No. 6,740,254) and polyketones, such as described in U.S. Pat. No. 6,777,514; and U.S. Patent Publication No. 2008-0242895. Epoxidized soybean oil, which has much longer alkyl groups (C_{16} to C_{18}), has been tried as a plasticizer, but is generally used as a PVC stabilizer. Stabilizers are used in much lower concentrations than plasticizers. US Patent Publication No. 2010-0159177 discloses triglycerides with a total carbon number of the triester groups between 20 and 25, produced by esterification of glycerol with a combination of acids derived from the hydroformylation and subsequent oxidation of C_3 to C_9 olefins, having excellent compatibility with a wide variety of resins and that can be made with a high throughput.

[0008] Typically, the best that has been achieved with substitution of the phthalate ester with an alternative material is a flexible PVC article having either reduced performance or poorer processability. Thus, existing efforts to make phthalate-free plasticizer systems for PVC have not proven to be entirely satisfactory, and so this is still an area of intense research.

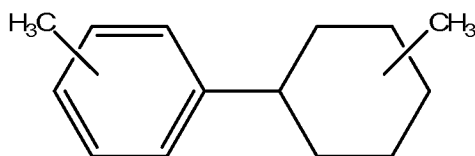
[0009] For example, in an article entitled "Esters of diphenic acid and their plasticizing properties", Kulev et al., *Izvestiya Tomskogo Politekhnikeskogo Instituta* (1961) 111, disclose that diisoamyl diphenate, bis(2-ethylhexyl) diphenate and mixed heptyl, octyl and nonyl diphenates can be prepared by esterification of diphenic acid, and allege that the resultant esters are useful as plasticizers for vinyl chloride. Similarly, in an article entitled "Synthesis of dialkyl diphenates and their properties", Shioda et al., *Yuki Gosei Kagaku Kyokaishi* (1959), 17, disclose that dialkyl diphenates of C_1 to C_8 alcohols, said to be useful as plasticizers for poly(vinyl chloride), can be formed by converting diphenic acid to diphenic anhydride and esterifying the diphenic anhydride. However, since these processes involve esterification of diphenic acid or anhydride, they necessarily result in 2,2'-substituted diesters of diphenic acid. Generally, such diesters having substitution on the 2-carbons have proven to be too volatile for use as plasticizers.

[0010] An alternative precursor for producing dialkyl diphenate esters having an

increased proportion of the less volatile 3,3', 3,4' and 4,4' diesters has now been developed. In particular, it has been found that by suitable selection of the catalyst, hydroalkylation of toluene can be used to produce a mixture of (methylcyclohexyl)toluene isomers predominantly containing isomers in which both of the methyl groups are at the 3- or 4-positions on their respective rings. On dehydrogenation, this isomer mixture can be converted to dimethylbiphenyl compounds which can then be oxidized to the corresponding carboxylic acids. Esterification of the carboxylic acid groups with an alcohol, such as an oxo alcohol, produces a mixture of dialkyl diphenate esters suitable for use as a plasticizer.

SUMMARY

[0011] In one aspect, the present disclosure is directed to a composition comprising a mixture of (methylcyclohexyl)toluene isomers having the following formula:

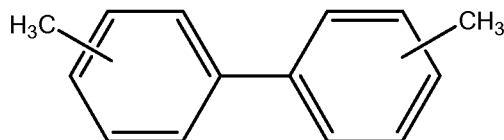


wherein said mixture comprises at least 50 wt% in total of the 3,3, 3,4 4,3 and 4,4-isomers of (methylcyclohexyl)toluene.

[0012] In one embodiment, the mixture comprises at least 10 wt% of 3,3-(methylcyclohexyl)toluene, at least 10 wt% of 3,4-(methylcyclohexyl)toluene, at least 10 wt% of 4,3-(methylcyclohexyl)toluene and at least 10 wt% of 4,4-(methylcyclohexyl)toluene. The mixture may also comprise less than 5% wt% of (1-methylcyclohexyl)toluene, (ethylcyclopentyl)toluenes and (dimethylcyclopentyl)toluenes combined and less than 10 wt% of γ -(x-ethylcyclopentenyl)toluene (x,y=2,3,4).

[0013] In one embodiment, the composition is produced by a process comprising contacting a feed comprising toluene with hydrogen in the presence of a hydroalkylation catalyst comprising an MCM-22 family molecular sieve and a hydrogenation component.

[0014] In another aspect, the present disclosure is directed to a composition comprising a mixture of dimethyl biphenyl isomers having the following formula:



wherein said mixture comprises at least 10 wt% of 3,3'-dimethyl biphenyl, at least 20 wt% of 3,4'-dimethyl biphenyl and at least 10 wt% of 4,4'-dimethyl biphenyl.

[0015] In further aspect, the present disclosure is directed to biphenyl carboxylic acids

and biphenyl esters produced from the (methylcyclohexyl)toluene isomer mixtures and the dimethyl biphenyl isomer mixtures described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Figure 1 is a bar graph comparing the amount of (dimethylcyclohexyl)toluenes produced in the hydroalkylation of toluene over the catalysts of Examples 1 to 4.

[0017] Figure 2 is a graph of toluene conversion against time on stream (TOS) in the hydroalkylation of toluene over the Pd-MCM-49 catalyst of Example 1.

[0018] Figure 3 is a graph of toluene conversion against time on stream (TOS) in the hydroalkylation of toluene over the Pd-beta catalyst of Example 2.

[0019] Figure 4 is a graph of toluene conversion against time on stream (TOS) in the hydroalkylation of toluene over the Pd-Y catalyst of Example 3.

[0020] Figure 5 is a graph of toluene conversion against time on stream (TOS) in the hydroalkylation of toluene over the Pd-WO₃/ZrO₂ catalyst of Example 4.

[0021] Figure 6 is a gas chromatographic mass spectrum of the product of the hydroalkylation of toluene over the Pd-MCM-49 catalyst of Example 1.

[0022] Figure 7 is a gas chromatographic mass spectrum of the product of the hydroalkylation of toluene over the Pd-beta catalyst of Example 2.

[0023] Figure 8 is a gas chromatographic mass spectrum of the product of the hydroalkylation of toluene over the Pd-Y catalyst of Example 3.

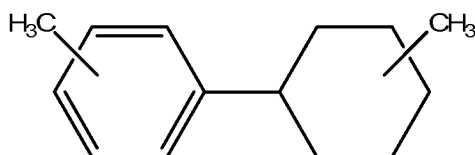
[0024] Figure 9 is a bar graph comparing the reaction effluents produced by the non-selective dehydrogenation of the (methylcyclohexyl)toluene products of Examples 1 and 2.

DETAILED DESCRIPTION OF THE EMBODIMENTS

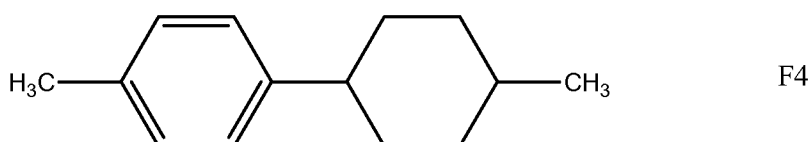
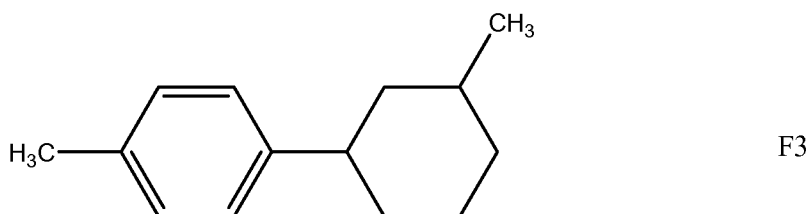
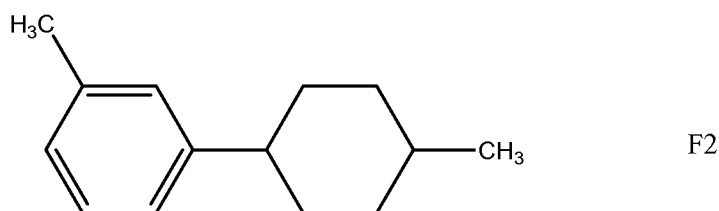
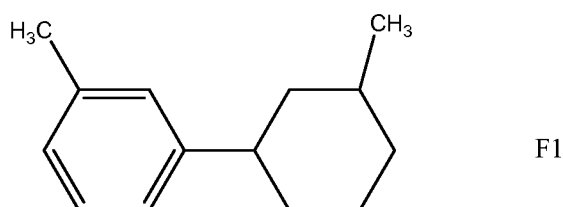
[0025] The present disclosure relates to a mixture of (methylcyclohexyl)toluene isomers comprising at least 50 wt% of the 3,3, 3,4 4,3 and 4,4-isomers produced by hydroalkylation of toluene over a catalyst comprising a molecular sieve of the MCM-22 and a hydrogenation component. The disclosure also relates to the dehydrogenation product of the (methylcyclohexyl)toluene isomer mixture and use of the dehydrogenation product as a precursor in the production of biphenylester-based plasticizers.

(Methylcyclohexyl)toluene Isomer Mixture

[0026] The present (methylcyclohexyl)toluene isomer mixture comprises compounds of the formula:



wherein the 3,3, 3,4 4,3 and 4,4-isomers collectively comprise at least 50 wt%, such as at least 60 wt%, for example at least 70 wt%, even at least 80 wt%, of the isomer mixture. In one embodiment, the mixture comprises at least 10 wt%, such as at least 15 wt%, of 3,3-(methylcyclohexyl)toluene (see Formula F1 below), at least 10 wt%, such as at least 15 wt%, of 3,4-(methylcyclohexyl)toluene (see Formula F2 below), at least 10 wt%, such as at least 15 wt%, of 4,3-(methylcyclohexyl)toluene (see Formula F3 below) and at least 10 wt%, such as at least 15 wt%, of 4,4-(methylcyclohexyl)toluene (see Formula F4 below).



[0027] Other isomers of (methylcyclohexyl)toluene may also be present in the mixture, but desirably, the total amount of isomers having a methyl group at the 2-position on either the phenyl or the cyclohexyl ring is less than 40 wt%, such as less than 30 wt%, of the mixture. In this respect, it is to be appreciated that the presence of a methyl group in the 2 position on either the cyclohexyl or phenyl ring is a precursor for the formation of fluorene and methyl fluorene. Fluorene is difficult to separate from the dimethylbiphenyl product and causes problems in the oxidation step and also in the plasticizers performance. It is therefore

advantageous to minimize the formation of isomers which have a methyl group in the ortho, 2 and benzylic positions.

[0028] In addition, the presence of a methyl group in the 1-position (quaternary carbon) on the cyclohexyl ring and the formation of γ -(α -ethylcyclopentenyl)toluene ($x,y=2,3,4$) are generally undesirable. Thus, (1-methylcyclohexyl)toluene tends to undergo ring isomerization to form (dimethylcyclopentyl)toluene and (ethylcyclopentyl)toluene which, on dehydrogenation, will generate diene by-products which are difficult to separate from the desired product and will also inhibit the subsequent oxidation reaction. In addition, γ -(α -ethylcyclopentenyl)toluene ($x,y=2,3,4$) cannot be converted to aromatic ring and, on dehydrogenation, will generate diene by-products which are difficult to separate from the desired product and will also inhibit the subject oxidation reaction. In one embodiment, the present isomer mixture comprises less than 5% wt% (1-methylcyclohexyl)toluene and (ethylcyclopentyl)toluenes or (dimethylcyclopentyl)toluene. In another embodiment, the isomer mixture comprises less than 10% wt% of γ -(α -ethylcyclopentenyl)toluene ($x,y=2,3,4$).

[0029] The present (methylcyclohexyl)toluene isomer mixture is produced by reacting toluene with hydrogen in the presence over a bifunctional catalyst comprising a molecular sieve of the MCM-22 family and a hydrogenation component. The process, which is normally called hydroalkylation, involves selective hydrogenation of part of the toluene to produce methylcyclohexene which then alkylates further toluene to produce isomers of (methylcyclohexyl)toluene.

[0030] The term "MCM-22 family material" (or "material of the MCM-22 family" or "molecular sieve of the MCM-22 family"), as used herein, includes one or more of:

- molecular sieves made from a common first degree crystalline building block unit cell, which unit cell has the MWW framework topology. (A unit cell is a spatial arrangement of atoms which if tiled in three-dimensional space describes the crystal structure. Such crystal structures are discussed in the "Atlas of Zeolite Framework Types", Fifth edition, 2001, the entire content of which is incorporated as reference);
- molecular sieves made from a common second degree building block, being a 2-dimensional tiling of such MWW framework topology unit cells, forming a monolayer of one unit cell thickness, preferably one c-unit cell thickness;
- molecular sieves made from common second degree building blocks, being layers of one or more than one unit cell thickness, wherein the layer of more than one unit cell thickness is made from stacking, packing, or binding at least two monolayers of one unit cell

thickness. The stacking of such second degree building blocks can be in a regular fashion, an irregular fashion, a random fashion, or any combination thereof; and

- molecular sieves made by any regular or random 2-dimensional or 3-dimensional combination of unit cells having the MWW framework topology.

[0031] Molecular sieves of MCM-22 family generally have an X-ray diffraction pattern including d-spacing maxima at 12.4 ± 0.25 , 6.9 ± 0.15 , 3.57 ± 0.07 and 3.42 ± 0.07 Angstrom. The X-ray diffraction data used to characterize the material are obtained by standard techniques using the K-alpha doublet of copper as the incident radiation and a diffractometer equipped with a scintillation counter and associated computer as the collection system. Molecular sieves of MCM-22 family include MCM-22 (described in U.S. Patent No. 4,954,325), PSH-3 (described in U.S. Patent No. 4,439,409), SSZ-25 (described in U.S. Patent No. 4,826,667), ERB-1 (described in European Patent No. 0293032), ITQ-1 (described in U.S. Patent No. 6,077,498), ITQ-2 (described in International Patent Publication No. WO97/17290), MCM-36 (described in U.S. Patent No. 5,250,277), MCM-49 (described in U.S. Patent No. 5,236,575), MCM-56 (described in U.S. Patent No. 5,362,697) and mixtures thereof.

[0032] Any known hydrogenation metal or compound thereof can be employed as the hydrogenation component of the catalyst, although suitable metals include palladium, ruthenium, nickel, zinc, tin, and cobalt, with palladium being particularly advantageous. In certain embodiments, the amount of hydrogenation metal present in the catalyst is between about 0.05 and about 10 wt %, such as between about 0.1 and about 5 wt %, of the catalyst.

[0033] The hydroalkylation catalyst may also include a binder such as clay, silica and/or metal oxides. The latter may be either naturally occurring or in the form of gelatinous precipitates or gels including mixtures of silica and metal oxides. Naturally occurring clays which can be used as a binder include those of the montmorillonite and kaolin families, which families include the subbentonites and the kaolins commonly known as Dixie, McNamee, Georgia and Florida clays or others in which the main mineral constituent is halloysite, kaolinite, dickite, nacrite or anauxite. Such clays can be used in the raw state as originally mined or initially subjected to calcination, acid treatment or chemical modification. Suitable metal oxide binders include silica, alumina, zirconia, titania, silica-alumina, silica-magnesia, silica-zirconia, silica-thoria, silica-beryllia, silica-titania as well as ternary compositions such as silica-alumina-thoria, silica-alumina-zirconia, silica-alumina-magnesia and silica-magnesia-zirconia.

[0034] In addition to the toluene and hydrogen, a diluent, which is substantially inert

under hydroalkylation conditions, may be supplied to the hydroalkylation reaction. In certain embodiments, the diluent is a hydrocarbon, in which the desired cycloalkylaromatic product is soluble, such as a straight chain paraffinic hydrocarbon, a branched chain paraffinic hydrocarbon, and/or a cyclic paraffinic hydrocarbon. Examples of suitable diluents are decane and cyclohexane. Although the amount of diluent is not narrowly defined, desirably the diluent is added in an amount such that the weight ratio of the diluent to the aromatic compound is at least 1:100; for example at least 1: 10, but no more than 10:1, desirably no more than 4:1.

[0035] The hydroalkylation reaction can be conducted in a wide range of reactor configurations including fixed bed, slurry reactors, and/or catalytic distillation towers. In addition, the hydroalkylation reaction can be conducted in a single reaction zone or in a plurality of reaction zones, in which at least the hydrogen is introduced to the reaction in stages. Suitable reaction temperatures are between about 100°C and about 400°C, such as between about 125°C and about 250°C, while suitable reaction pressures are between about 100 and about 7,000 kPa, such as between about 500 and about 5,000 kPa. The molar ratio of hydrogen to toluene is typically from about 0.15:1 to about 15:1.

[0036] In the present process, it is found that MCM-22 family molecular sieves are particularly active and stable catalysts for the hydroalkylation of toluene. In addition, catalysts containing MCM-22 family molecular sieves exhibit particular selectivity to the 3,3'-dimethyl, the 3,4'-dimethyl, the 4,3'-dimethyl and the 4,4'-dimethyl isomers in the hydroalkylation product, while at the same time reducing the formation of fully saturated and heavy by-products. For example, using an MCM-22 family molecular sieve with a toluene feed, it is found that the hydroalkylation reaction product may comprise:

- at least 50 wt% of the 3,3, 3,4, 4,3 and 4,4-isomers of (methylcyclohexyl)toluene based on the total weight of all the (methylcyclohexyl)toluene isomers;
- less than 30 wt% of methylcyclohexane and less than 2% of dimethylbicyclohexane compounds;
- and less than 1 wt% of compounds containing in excess of 14 carbon atoms.

Dehydrogenation of Hydroalkylation Product

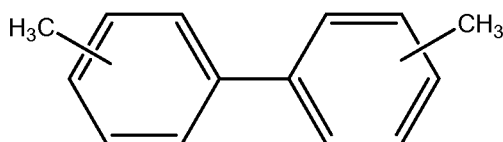
[0037] The major components of the hydroalkylation reaction effluent are (methylcyclohexyl)toluenes and/or (dimethylcyclohexyl)xylenes, unreacted aromatic feed (toluene and/or xylene) and fully saturated single ring by-products (methylcyclohexane and dimethylcyclohexane). The unreacted feed and light by-products can readily be removed

from the reaction effluent by, for example, distillation. The unreacted feed can then be recycled to the hydroalkylation reactor, while the saturated by-products can be dehydrogenated to produce additional recyclable feed.

[0038] The remainder of the hydroalkylation reaction effluent, composed mainly of (methylcyclohexyl)toluenes and/or (dimethylcyclohexyl)xylenes, is then dehydrogenated to produce the corresponding methyl-substituted biphenyl compounds. The dehydrogenation is conveniently conducted at a temperature from about 200°C to about 600°C and a pressure from about 100 kPa to about 3550 kPa (atmospheric to about 500 psig) in the presence of dehydrogenation catalyst. A suitable dehydrogenation catalyst comprises one or more elements or compounds thereof selected from Group 10 of the Periodic Table of Elements, for example platinum, on a support, such as silica, alumina or carbon nanotubes. In one embodiment, the Group 10 element is present in amount from 0.1 to 5 wt % of the catalyst. In some cases, the dehydrogenation catalyst may also include tin or a tin compound to improve the selectivity to the desired methyl-substituted biphenyl product. In one embodiment, the tin is present in amount from 0.05 to 2.5 wt % of the catalyst.

[0039] As used herein, the numbering scheme for the Periodic Table Groups is the new notation as disclosed in Chemical and Engineering News, 63(5), 27 (1985).

[0040] The product of the dehydrogenation step comprises a mixture of dimethyl biphenyl isomers having the following formula:



wherein the mixture comprises at least 10 wt%, such as at least 15 wt%, of 3,3'-dimethyl biphenyl, at least 20 wt%, such as at least 30 wt%, of 3,4-dimethyl biphenyl and at least 10 wt% such as at least 15 wt%, of 4,4'-dimethyl biphenyl. In one embodiment, the total amount of 2,2'-dimethyl biphenyl, 2,3'-dimethyl biphenyl and 2,4'-dimethyl biphenyl in the mixture is less than 30 wt%, such as less than 25 wt%, of said mixture. In addition, the dehydrogenation product, typically contains less than 5 wt%, such as less than 1 wt%, of fluorene and methyl fluorenes combined and less than 10 wt%, such as less than 5 wt%, of monomethyl biphenyl compounds. The addition of Sn to the dehydrogenation catalyst is found to improve the selectivity of the desired 3,3'-, 3,4'- and 4,4'-dimethyl biphenyl isomers and reduce the formation of the fluorine, methyl fluorine and monomethyl biphenyl by-products.

Production of Biphenyl Esters

[0041] The methyl-substituted biphenyl compounds produced by the dehydrogenation reaction can readily be converted ester plasticizers by a process comprising oxidation to produce the corresponding carboxylic acids followed by esterification with an alcohol.

[0042] The oxidation can be performed by any process known in the art, such as by reacting the methyl-substituted biphenyl compounds with an oxidant, such as oxygen, ozone or air, or any other oxygen source, such as hydrogen peroxide, in the presence of a catalyst at temperatures from 30°C to 300°C, such as from 60°C to 200°C. Suitable catalysts comprise Co or Mn or a combination of both metals.

[0043] The resulting carboxylic acids can then be esterified to produce biphenyl ester plasticizers by reaction with one or more C₄ to C₁₄ alcohols. Suitable esterification conditions are well-known in the art and include, but are not limited to, temperatures of 0-300 °C and the presence or absence of homogeneous or heterogeneous esterification catalysts, such as Lewis or Bronsted acid catalysts. Suitable alcohols are "oxo-alcohols", by which is meant an organic alcohol, or mixture of organic alcohols, which is prepared by hydroformylating an olefin, followed by hydrogenation to form the alcohols. Typically, the olefin is formed by light olefin oligomerization over heterogeneous acid catalysts, which olefins are readily available from refinery processing operations. The reaction results in mixtures of longer-chain, branched olefins, which subsequently form longer chain, branched alcohols, as described in U.S. Pat. No. 6,274,756, incorporated herein by reference in its entirety. Another source of olefins used in the OXO process are through the oligomerization of ethylene, producing mixtures of predominately straight chain alcohols with lesser amounts of lightly branched alcohols.

[0044] The biphenyl ester plasticizers of the present application find use in a number of different polymers, such as vinyl chloride resins, polyesters, polyurethanes, ethylene-vinyl acetate copolymers, rubbers, poly(meth)acrylics and mixtures thereof.

[0045] The invention will now be more particularly described with reference to the following non-limiting Examples.

Example 1: Synthesis of 0.3%Pd/MCM-49 Catalyst

[0046] 80 parts MCM-49 zeolite crystals are combined with 20 parts pseudoboehmite alumina, on a calcined dry weight basis. The MCM-49 and pseudoboehmite alumina dry powder is placed in a muller and mixed for about 10 to 30 minutes. Sufficient water and 0.05% polyvinyl alcohol is added to the MCM-49 and alumina during the mixing process to produce an extrudable paste. The extrudable paste is formed into a 1/20 inch (0.13 cm)

quadrulobe extrudate using an extruder and the resulting extrudate is dried at a temperature ranging from 250°F to 325°F (120°C to 163°C). After drying, the dried extrudate is heated to 1000°F (538°C) under flowing nitrogen. The extrudate is then cooled to ambient temperature and humidified with saturated air or steam.

[0047] After the humidification, the extrudate is ion exchanged with 0.5 to 1 N ammonium nitrate solution. The ammonium nitrate solution ion exchange is repeated. The ammonium nitrate exchanged extrudate is then washed with deionized water to remove residual nitrate prior to calcination in air. After washing the wet extrudate, it is dried. The exchanged and dried extrudate is then calcined in a nitrogen/air mixture to a temperature 1000°F (538°C). Afterwards, the calcined extrudate is cooled to room temperature. The 80% MCM-49, 20% Al₂O₃ extrudate was incipient wetness impregnated with a palladium (II) chloride solution (target: 0.30% Pd) and then dried overnight at 121°C. The dried catalyst was calcined in air at the following conditions: 5 volumes air per volume catalyst per minute, ramp from ambient to 538°C at 1 °C/min and hold for 3 hours.

Example 2: Synthesis of 0.3%Pd/Beta Catalyst

[0048] 80 parts beta zeolite crystals are combined with 20 parts pseudoboehmite alumina, on a calcined dry weight basis. The beta and pseudoboehmite are mixed in a muller for about 15 to 60 minutes. Sufficient water and 1.0% nitric acid is added during the mixing process to produce an extrudable paste. The extrudable paste is formed into a 1/20 inch quadrulobe extrudate using an extruder. After extrusion, the 1/20th inch quadrulobe extrudate is dried at a temperature ranging from 250°F to 325°F (120°C to 163°C). After drying, the dried extrudate is heated to 1000°F (538°C) under flowing nitrogen and then calcined in air at a temperature of 1000°F (538°C). Afterwards, the calcined extrudate is cooled to room temperature. The 80% Beta, 20% Al₂O₃ extrudate was incipient wetness impregnated with a tetraammine palladium (II) nitrate solution (target: 0.30% Pd) and then dried overnight at 121°C. The dried catalyst was calcined in air at the following conditions: 5 volumes air per volume catalyst per minute, ramp from ambient to 538°C at 1°C/min and hold for 3 hours.

Example 3: Synthesis of 0.3%Pd/USY Catalyst

[0049] 80 parts Zeolyst CBV-720 ultrastable Y zeolite crystals are combined with 20 parts pseudoboehmite alumina on a calcined dry weight basis. The USY and pseudoboehmite are mixed for about 15 to 60 minutes. Sufficient water and 1.0% nitric acid is added during the mixing process to produce an extrudable paste. The extrudable paste is formed into a 1/20 inch quadrulobe extrudate using an extruder. After extrusion, the 1/20th inch quadrulobe extrudate is dried at a temperature ranging from 250°F to 325°F (120°C to

163°C). After drying, the dried extrudate is heated to 1000°F (538°C) under flowing nitrogen and then calcined in air at a temperature of 1000°F (538°C). The 80% CBV-720 USY, 20% Al₂O₃ extrudate was incipient wetness impregnated with a palladium (II) chloride solution (target: 0.30% Pd) and then dried overnight at 121°C. The dried catalyst was calcined in air at the following conditions: 5 volumes air per volume catalyst per minute, ramp from ambient to 538°C at 1°C/min and hold for 3 hours.

Example 4: Synthesis of 0.3%Pd/W-Zr Catalyst

[0050] A WO₃/ZrO₂ extrudate (11.5% W, balance Zr) 1/16" cylinder was obtained from Magnesium Elektron in the form of a 1/16 inch (0.16 cm) diameter extrudate. The WO₃/ZrO₂ extrudate was calcined in air for 3 hours at 538°C. On cooling, the calcined extrudate was incipient wetness impregnated with a palladium (II) chloride solution (target: 0.30% Pd) and then dried overnight at 121°C. The dried catalyst was calcined in air at the following conditions: 5 volumes air per volume catalyst per minute, ramp from ambient to 538°C at 1°C/min and hold for 3 hours.

Example 4: Hydroalkylation Catalyst Testing

[0051] Each of the catalyst of Examples 1 to 4 was then tested in the hydroalkylation of a toluene feed using the reactor and process described below.

[0052] The reactor comprised a stainless steel tube having an outside diameter of: 3/8 inch (0.95 cm), a length of 20.5 inch (52 cm) and a wall thickness of 0.35 inch (0.9 cm). A piece of stainless steel tubing having a length of 8¾ inch (22 cm) and an outside diameter of: 3/8 inch (0.95 cm) and a similar length of ¼ inch (0.6 cm) tubing of were used in the bottom of the reactor (one inside of the other) as a spacer to position and support the catalyst in the isothermal zone of the furnace. A ¼ inch (0.6 cm) plug of glass wool was placed on top of the spacer to keep the catalyst in place. A 1/8 inch (0.3 cm) stainless steel thermo-well was placed in the catalyst bed to monitor temperature throughout the catalyst bed using a movable thermocouple.

[0053] The catalyst was sized to 20/40 sieve mesh or cut to 1:1 length to diameter ratio, dispersed with quartz chips (20/40 mesh) then loaded into the reactor from the top to a volume of 5.5 cc. The catalyst bed typically was 15 cm. in length. The remaining void space at the top of the reactor was filled with quartz chips, with a ¼ plug of glass wool placed on top of the catalyst bed being used to separate quartz chips from the catalyst. The reactor was installed in a furnace with the catalyst bed in the middle of the furnace at a pre-marked isothermal zone. The reactor was then pressure and leak tested typically at 300 psig (2170 kPa).

[0054] The catalyst was pre-conditioned in situ by heating to 25°C to 240°C with H₂ flow at 100 cc/min and holding for 12 hours. A 500 cc ISCO syringe pump was used to introduce a chemical grade toluene feed to the reactor. The feed was pumped through a vaporizer before flowing through heated lines to the reactor. A Brooks mass flow controller was used to set the hydrogen flow rate. A Grove “Mity Mite” back pressure controller was used to control the reactor pressure typically at 150 psig (1135 kPa). GC analyses were taken to verify feed composition. The feed was then pumped through the catalyst bed held at the reaction temperature of 120°C to 180°C at a WHSV of 2 and a pressure of 15-200 psig (204-1480 kPa). The liquid products exiting the reactor flowed through heated lines routed to two collection pots in series, the first pot being heated to 60°C and the second pot cooled with chilled coolant to about 10°C. Material balances were taken at 12 to 24 hrs intervals. Samples were taken and diluted with 50% ethanol for analysis. An Agilent 7890 gas chromatograph with FID detector was used for the analysis. The non-condensable gas products were routed to an on line HP 5890 GC.

The analysis is done on an Agilent 7890 GC with 150 vial sample tray.

Inlet Temp: 220°C

Detector Temp: 240°C (Col + make up = constant)

Temp Program: Initial temp 120°C hold for 15 min., ramp at 2°C/min to 180°C , hold 15 min; ramp at 3°C/min. to 220°C and hold till end.

Column Flow: 2.25 ml/min. (27 cm/sec); Split mode, Split ratio 100:1

Injector: Auto sampler (0.2 µl).

Column Parameters:

Two columns joined to make 120 Meters (coupled with Agilent ultimate union, deactivated).

Column # Front end: Supelco β-Dex 120; 60m x 0.25 mm x 0.25 µm film joined to Column # 2 back end: γ-Dex 325; 60 m x 0.25 mm x 0.25 µm film

[0055] The results of the hydroalkylation testing are summarized in Figures 1 to 4 and Table 1.

Table 1

Example	Catalyst	Toluene conversion	Selectivity to methylcyclohexane	Selectivity to dimethylbi(cyclohexane)
1	0.3%Pd-MCM49	37%	23%	1.40%
2	0.3% Pd/Beta	40%	65%	1.60%
3	0.3% Pd/Y	80%	75%	3.70%
4	0.3% WO ₃ /ZrO ₂	13%	35%	1.75%

[0056] As can be seen from Table 1, although the Pd/MCM-49 catalyst is less active than the Pd/Y catalyst, it has much lower selectivity towards the production of the fully saturated by-products, methylcyclohexane and dimethylbi(cyclohexane) than either Pd/Y or Pd/beta. In addition, the data shown in Figure 1 clearly demonstrate that Pd/MCM-49 provides the lowest yield loss, less than 1 wt% of total converted feed, to dialkylate products. The data shown in Figures 2 to 5 demonstrate that Pd/MCM-49 has improved stability and catalyst life as compared with the other catalysts tested. It is believed that the stability is related to the formation of heavies which remain on the surface of the catalyst and react further to create coke which prevents the access to the acid and hydrogenation sites.

[0057] The GC mass spectra in Figures 6 to 8 show that the hydroalkylated product of Examples contained the compounds listed in Table 2.

Table 2

	MCM-49 HA product	Beta HA product
y-(x-methylcyclohexyl)toluene (x,y=2,3,4)	89.29%	39.82%
y-(1-methylcyclohexyl)toluene (y=2, 4)	3.03%	53.26%
y-(x-ethylcyclopentenyl)toluene (x,y=2,3,4)	7.68%	6.92%

[0058] Table 2 clearly shows that the MCM-49 catalyst can provide much higher amounts of the desired hydroalkylation products (y-(x-methylcyclohexyl)toluene (x,y=2,3,4)) than the zeolite beta catalyst, and much lower amount of undesired y-(1-methylcyclohexyl)toluene (y=2, 4). The amount of y-(x-ethylcyclopentenyl)toluene (x,y=2,3,4) are similar for both the MCM-49 and beta catalysts.

Example 5: Dehydrogenation of Methylcyclohexyltoluene

[0059] The same reactor, catalyst and analytical configuration as described above was used to perform dehydrogenation tests on the methylcyclohexyltoluene products produced in Example 4 from the Pd/MCM-49 and Pd/beta catalysts of Examples 1 and 2, except the dehydrogenation catalyst was pre-conditioned in situ by heating to 375°C to 460 °C with H₂ flow at 100 cc/min and holding for 2 hours. In addition, in the dehydrogenation tests the catalyst bed was held at the reaction temperature of 375°C to 460 °C at a WHSV of 2 and a pressure of 100 psig (790 kPa).

[0060] In a first set of tests, the dehydrogenation was conducted at a temperature of 425°C using a selective dehydrogenation catalyst comprising bimetallic catalyst e.g., Pt/Sn,

on a support. The results of the tests are summarized in Table 3 below:

Table 3

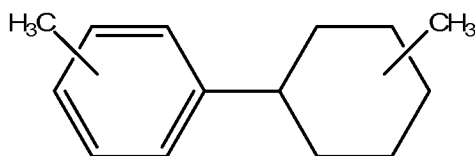
	MCM-49 HA product over selective dehydrogenation catalyst	Beta HA product over selective dehydrogenation catalyst
3-methyl biphenyl	0.70%	2.47%
4- methyl biphenyl	0.79%	4.98%
2,2' dimethyl biphenyl	1.21%	1.04%
2,3' dimethyl biphenyl	9.52%	8.42%
2,4' dimethyl biphenyl	13.14%	12.64%
3,3' dimethyl biphenyl	15.98%	13.21%
3,4' dimethyl biphenyl	39.64%	36.26%
4,4' dimethyl biphenyl	18.76%	18.19%
fluorene	0.00%	0.93%
methyl fluorenes	0.26%	1.87%

[0061] In a second set of tests, the dehydrogenation was conducted at a temperature of 425°C using a non-selective dehydrogenation catalyst comprising Pt on a support. The results of the tests are summarized in Figure 9.

[0062] The data clearly shows that dehydrogenation of the MCM-49 hydroalkylation products provides less mono methyl biphenyl, less of the 2',3 and 2',4 isomers which are the precursor for the formation of fluorene and methyl fluorene and much less the fluorene and methyl fluorine as compared with dehydrogenation of the zeolite beta hydroalkylation products.

[0063] While various embodiments have been described, it is to be understood that further embodiments will be apparent to those skilled in the art and that such embodiments are to be considered within the purview and scope of the appended claims. Such further embodiments include those defined in the following paragraphs:

Paragraph 1. A composition comprising a mixture of (methylcyclohexyl)toluene isomers having the following formula:



wherein said mixture comprises at least 50 wt%, preferably at least 60 wt%, in total of the

3,3, 3,4 4,3 and 4,4-isomers of (methylcyclohexyl)toluene.

Paragraph 2. The composition of paragraph 1, wherein said mixture comprises at least 10 wt% of 3,3-(methylcyclohexyl)toluene, at least 10 wt% of 3,4-(methylcyclohexyl)toluene, at least 10 wt% of 4,3-(methylcyclohexyl)toluene and at least 10 wt% of 4,4-(methylcyclohexyl)toluene.

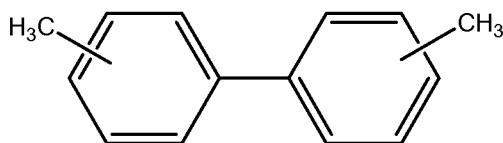
Paragraph 3. The composition of paragraph 1 or 2, wherein the total amount of isomers having a methyl group at the 2-position on either the phenyl or the cyclohexyl ring is less than 40 wt%, preferably less than 30 wt%, of said mixture.

Paragraph 4. The composition of any one of paragraphs 1 to 3, wherein the total amount of (1-methylcyclohexyl)toluene, (ethylcyclopentyl)toluenes and (diethylcyclopentyl)toluenes in said mixture is less than 5 wt%.

Paragraph 5. The composition of any one of paragraphs 1 to 4, wherein the mixture comprises less than 10 wt% of γ -(x-ethylcyclopentenyl)toluene (x,y=2,3,4).

Paragraph 6. The composition of any one of paragraphs 1 to 5, wherein the composition is produced by a process comprising contacting a feed comprising toluene with hydrogen in the presence of a hydroalkylation catalyst comprising an MCM-22 family molecular sieve and a hydrogenation component.

Paragraph 7. A composition comprising a mixture of dimethyl biphenyl isomers having the following formula:



wherein said mixture comprises at least 10 wt% of 3,3-dimethyl biphenyl, at least 20 wt% of 3,4-dimethyl biphenyl and at least 10 wt% of 4,4-dimethyl biphenyl.

Paragraph 8. The composition of paragraph 7, wherein said mixture comprises at least 15 wt% of 3,3-dimethyl biphenyl, at least 30 wt% of 3,4-dimethyl biphenyl and at least 15 wt% of 4,4-dimethyl biphenyl.

Paragraph 9. The composition of paragraph 7 or 8, wherein the total amount of 2,2-dimethyl biphenyl, 2,3-dimethyl biphenyl and 2,4-dimethyl biphenyl in said mixture is less than 30 wt%, preferably less than 25 wt%, of said mixture.

Paragraph 10. The composition of any one of paragraphs 7 to 9, wherein the composition comprises less than 5 wt%, preferably less than 1 wt%, of fluorene and methyl fluorenes combined.

Paragraph 11. The composition of any one of paragraphs 7 to 10, wherein the

composition comprises less than 10 wt% preferably less than 5 wt%, of monomethyl biphenyl compounds.

Paragraph 12. The composition of any one of paragraphs 7 to 11, wherein the composition is produced by a process comprising:

(a) contacting a feed comprising toluene with hydrogen in the presence of a hydroalkylation catalyst under conditions effective to produce a hydroalkylation reaction product comprising (methylcyclohexyl)toluenes; and

(b) dehydrogenating at least part of the hydroalkylation reaction product.

Paragraph 13. A composition comprising a mixture of biphenyl carboxylic acids produced by oxidizing at least part of the composition of any one of paragraphs 7 to 12.

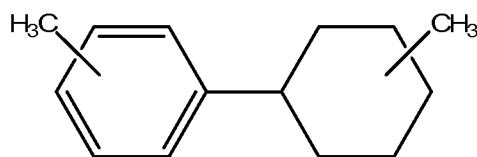
Paragraph 14. A composition comprising a mixture of biphenyl esters produced by reacting at least part of the composition of paragraph 13 with at least one alcohol, preferably having 4 to 14 carbon atoms.

Paragraph 15. The composition of paragraph 14, wherein said at least one alcohol comprises an oxo alcohol.

[0064] All documents described herein are incorporated by reference herein, including any priority documents and/or testing procedures to the extent they are not inconsistent with this text, provided however that any priority document not named in the initially filed application or filing documents is NOT incorporated by reference herein. As is apparent from the foregoing general description and the specific embodiments, while forms of the invention have been illustrated and described, various modifications can be made without departing from the spirit and scope of the invention. Accordingly, it is not intended that the invention be limited thereby. Likewise, the term "comprising" is considered synonymous with the term "including" for purposes of Australian law. Likewise whenever a composition, an element or a group of elements is preceded with the transitional phrase "comprising", it is understood that we also contemplate the same composition or group of elements with transitional phrases "consisting essentially of," "consisting of", "selected from the group of consisting of," or "is" preceding the recitation of the composition, element, or elements and vice versa.

CLAIMS

1. A composition comprising a mixture of (methylcyclohexyl)toluene isomers having the following formula:



wherein said mixture comprises at least 50 wt% in total of the 3,3, 3,4 4,3 and 4,4-isomers of (methylcyclohexyl)toluene.

2. The composition of claim 1, wherein said mixture comprises at least 60 wt% in total of the 3,3, 3,4 4,3 and 4,4-isomers of (methylcyclohexyl)toluene.

3. The composition of claim 1, wherein said mixture comprises at least 10 wt% of 3,3-(methylcyclohexyl)toluene, at least 10 wt% of 3,4-(methylcyclohexyl)toluene, at least 10 wt% of 4,3-(methylcyclohexyl)toluene and at least 10 wt% of 4,4-(methylcyclohexyl)toluene.

4. The composition of claim 1, wherein the total amount of isomers having a methyl group at the 2-position on either the phenyl or the cyclohexyl ring is less than 40 wt% of said mixture.

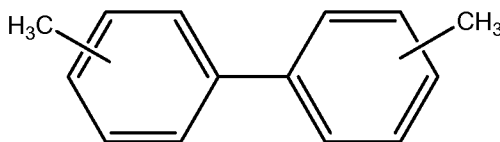
5. The composition of claim 1, wherein the total amount of isomers having a methyl group at the 2-position on either the phenyl or the cyclohexyl ring is less than 30 wt% of said mixture.

6. The composition of claim 1, wherein the total amount of (1-methylcyclohexyl)toluene, (ethylcyclopentyl)toluenes and (diethylcyclopentyl)toluenes in said mixture is less than 5 wt%.

7. The composition of claim 1, wherein the mixture comprises less than 10 wt% of y-(x-ethylcyclopentenyl)toluene (x,y=2,3,4).

8. The composition of claim 1, wherein the composition is produced by a process comprising contacting a feed comprising toluene with hydrogen in the presence of a hydroalkylation catalyst comprising an MCM-22 family molecular sieve and a hydrogenation component.

9. A composition comprising a mixture of dimethyl biphenyl isomers having the following formula:



wherein said mixture comprises at least 10 wt% of 3,3-dimethyl biphenyl, at least 20 wt% of 3,4-dimethyl biphenyl and at least 10 wt% of 4,4-dimethyl biphenyl.

10. The composition of claim 9, wherein said mixture comprises at least 15 wt% of 3,3-dimethyl biphenyl, at least 30 wt% of 3,4-dimethyl biphenyl and at least 15 wt% of 4,4-dimethyl biphenyl.

11. The composition of claim 9, wherein the total amount of 2,2-dimethyl biphenyl, 2,3-dimethyl biphenyl and 2,4-dimethyl biphenyl in said mixture is less than 30 wt% of said mixture.

12. The composition of claim 9, wherein the total amount of 2,2'-dimethyl biphenyl, 2,3'-dimethyl biphenyl and 2,4'-dimethyl biphenyl in said mixture is less than 25 wt% of said mixture.

13. The composition of claim 9, wherein the composition comprises less than 5 wt% of fluorene and methyl fluorenes combined.

14. The composition of claim 9, wherein the composition comprises less than 1 wt% of fluorene and methyl fluorenes combined.

15. The composition of claim 9, wherein the composition comprises less than 10 wt% of monomethyl biphenyl compounds.

16. The composition of claim 9, wherein the composition comprises less than 5 wt% of monomethyl biphenyl compounds.

17. The composition of claim 9, wherein the composition is produced by a process comprising:

(a) contacting a feed comprising toluene with hydrogen in the presence of a hydroalkylation catalyst under conditions effective to produce a hydroalkylation reaction product comprising (methylcyclohexyl)toluenes; and

(b) dehydrogenating at least part of the hydroalkylation reaction product.

18. The composition of claim 17, wherein said hydroalkylation catalyst comprises an MCM-22 family molecular sieve and a hydrogenation component.

19. A composition comprising a mixture of biphenyl carboxylic acids produced by oxidizing at least part of the composition of claim 9.

20. A composition comprising a mixture of biphenyl esters produced by reacting at least part of the composition of claim 19 with at least one alcohol.
21. The composition of claim 20, wherein said at least one alcohol has 4 to 14 carbon atoms.
22. The composition of claim 21, wherein said at least one alcohol comprises an oxo alcohol.