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(21) International Application Number: PCT/US96/11401 (22) International Filing Date: 10 July 1996 (10.07.96) (30) Priority Data: 08/499,932 10 July 1995 (10.07.95) US (71) Applicant: THE TRUSTEES OF PRINCETON UNIVERSITY [US/US]; New South Building, Fifth floor, P.O. Box 36, Princeton, NJ 08544 (US). (71)(72) Applicant and Inventor: SCHWARTZ, Jeffrey [US/US]; 55 Locust Lane, Princeton, NJ 08540 (US). (74) Agents: COLLINS, Bruce, M. et al.; Mathews, Woodbridge & Collins, P.A., Suite 306, 100 Thanet Circle, Princeton, NJ 08540 (US).		(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SI, SK, TJ, TT, UA, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i>
(54) Title: PROCESS FOR REDUCING ORGANIC POLLUTANTS		
(57) Abstract Nitrogen-containing substituents of aliphatic or aromatic compounds can be reduced by treatment with a reagent comprising (i) at least one complex of a transition metal of group 4 or 5 with a multidentate or unidentate organic or inorganic ligand and (ii) a reducing agent. The reaction is conducted optionally in the presence of an aliphatic or aromatic amine, and/or in the presence of an inert organic solvent. The reaction process also reduces double bonds in polynuclear aromatic hydrocarbons.		

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PROCESS FOR REDUCING ORGANIC POLLUTANTS

Cross-Reference to Related Application

This is a continuation-in-part of Serial No. 08/211,983
5 filed August 15, 1994, the disclosure of which is incorpo-
rated in its entirety herein by reference.

Background of the Invention

In Serial No. 08/211,983 a process is described for the
reduction of the chlorine content of polychlorinated
10 hydrocarbons such as, for example, polychlorinated benzene
and polychlorinated biphenyls. The process utilizes a
reagent comprising (i) at least one complex of a transition
metal of group 4 or 5 with a multidentate or unidentate
organic or inorganic ligand and (ii) a reducing agent such
15 as a hydridoborate. Typical of the first component is bis-
(η^5 -cyclopentadienyl)titanium dichloride (titanocene
dichloride) while sodium tetrahydridoborate is
representative of the latter.

Various methods are employed in reducing nitrogen-
20 containing substituents on aliphatic and aromatic compounds
to amines. For example, the reduction of nitro substituents
to amines involves reducing agents such as iron, zinc, or
tin with acid; hydrogen with a catalyst such as platinum,
palladium, or nickel; hydrogen with a catalyst; and
25 sulfides.

Nitroso substituents and hydroxylamines can be reduced
to amines by the same reagents which reduce nitro compounds.

N-Nitroso compounds are similarly reduced to hydrazines. Azo, azoxy, and hydrazo substituents can be reduced to amines using metals, notably zinc, and acids, and sodium hydrosulfate as reducing agents. Diborane reduces azo substituents to amines.

Nitro substituents have been reduced to intermediates within the sequence, such as azoxy, with sodium arsenite, sodium ethoxide, glucose, and potassium borofluoride. The most common reducing agents for reducing nitro substituents to azo compounds are lithium aluminum hydride, and zinc and alkali. Other intermediate substituents within the sequence, such as nitroso, are reduced to azo compounds with lithium aluminum hydride as well. Zinc and sodium are the most common agents used in reducing nitro substituents to hydrazo compounds. Nitro substituents have also been reduced to hydrazo compounds electrolytically, or with lithium aluminum hydride mixed with a metal chloride such as titanium tetrachloride or vanadium trichloride, or hydrazine hydrate and Raney nickel.

On aliphatic compounds, lithium aluminum hydride reduces nitro substituents to amines, but nitro substituents on aromatic compounds are reduced to azo compounds. Lithium aluminum hydride does not generally reduce azo compounds (these are the products from lithium aluminum hydride reduction of nitro compounds), but these substituents can be reduced to hydrazo compounds by catalytic hydrogenation.

Most metal hydrides, such as sodium borohydride, reduce nitro substituents on aromatic compounds to azo and azoxy compounds, leaving the aromatic ring intact.

Detailed Description

The present process is based on the discovery that nitrogen-containing substituents on aliphatic or aromatic compounds are reduced from an oxidative state higher than that of a primary amine to a lower oxidative state. The resulting compounds are readily converted into biodegradable amines upon hydrolysis.

The first component will contain a substantially nontoxic transition metal of Group 4 or 5 (IVa or Va) and will form a complex with multidentate and unidentate organic and inorganic ligands. Particularly preferred transition metals are titanium and zirconium. Preferred ligands include benzoates, chlorides, cyclopentadienides, substituted cyclopentadienides, indenides, substituted indenides, salens, porphyrins, tris(pyrazolyl) borates, poly(alkylaminos), poly(thioalkyls), and mixtures thereof. One highly effective subclass are the organometallic complexes of titanium and zirconium such as bis-(η^5 -cyclopentadienyl)titanium dichloride, bis-(η^5 -cyclopentadienyl)zirconium dichloride, η^5 -cyclopentadienyl zirconium trichloride, and η^5 -cyclopentadienyltitanium trichloride. Particularly useful in view of its currently relatively low cost and performance is bis-(η^5 -cyclopentadienyl)titanium dichloride, also known as titanocene dichloride.

The nitrogen containing substituents which are reduced by the process are nitro, nitroso, hydroxylamino, azo, azoxy, hydrazo, and the like.

Compounds with nitrogen containing substituents reduced by the process include highly explosive pollutants such as 2,4,6-tri-nitrotoluene, 1,3,5,7-tetranitrooctahydro-1,3,5,7-tetrazocine, hexahydro-1,3,5-trinitro-1,3,5-triazine, 2,4,6-trinitrophenol or glyceryl nitrate.

Nitrogen containing substituents on aliphatic or aromatic compounds are reduced in the process. The metal-catalyzed reduction leads to easily biodegradable organic products. Subjecting the reduced products of the reaction to hydrolysis forms titanium dioxide and borate by-products.

The process is effected in a single step. Nitrogen-containing substituents on compounds can be rapidly reduced to primary amines using the present system. Azobenzene is rapidly reduced to aniline. Diphenylhydrazine is even more rapidly reduced to aniline under the recited catalytic conditions. Intermediate compounds within the reduction sequence having nitrogen-containing substituents such as nitroso, hydroxylamino, azoxy, azo, and hydrazo species are also reduced by the catalyst system.

Addition of an amine to the reaction is optional, since the nitrogen inherently present in the nitrogen-containing substituents activates the metal complex.

When added, the additional amine can be any aliphatic amine such as trimethylamine, triethylamine, dimethylethylamine, etc., an aromatic additive amine such as N,N-dimethylaniline, N,N-dimethylnaphthylamine, etc., or an aromatic or nonaromatic heterocyclic amine such as pyridine, 1-methylimidazole, quinoline, piperidine, etc. Although primary and secondary amines can be employed, tertiary amines are preferred. Generally, a molar excess of the amine is employed.

The reaction can be conducted in a variety of inert organic solvents such as diglyme, triglyme, bis-(2-ethoxyethyl)ether, tetrahydrofuran, dimethylsulfoxide, ethylene glycol dimethyl ether and the like. Particularly preferred are ethers such as diglyme. In addition, an active solvent useful in the process is dimethylformamide.

Optionally a phase-transfer agent can be added to assist in dissolution of the reactants, particularly the hydridoborate. Typical of these are the methyltri(C₈-C₁₀alkyl)ammonium chlorides.

5 Reaction times will depend on the reactants and temperature. The reaction thus can be conducted at temperatures of from about 50°C to about 150°C. Preferably, the reaction is conducted at temperatures of 120°C to about 130°C. Reduction of azobenzene at 125°C is substantially complete
10 in about one hour. Hydrazobenzene, when subjected to the identical temperature conditions, is reduced to azobenzene in about 30 minutes. In contrast, 2-(diethylamino)azobenzene takes longer to be reduced than azobenzene. Nitrobenzene is reduced to a mixture of aniline and
15 azobenzene after about thirty minutes at 125°C. The resulting azobenzene can then be further reduced to aniline. The degree of reduction can be monitored using conventional analytical techniques such as gas chromatography.

20 In a further embodiment, the process reduces double bonds in polynuclear aromatic hydrocarbons from a higher oxidative state to a lower oxidative state. The resulting compounds are more readily biodegradable.

25 In the reduction of polychlorinated hydrocarbons, the reaction was driven overall by the removal of a halide group. However, certain polynuclear aromatic compounds, such as, for example, anthracene and naphthacene, do not have substituent groups such as these. When reducing polynuclear aromatic hydrocarbons, preferably a proton source, such as aliphatic alcohols having a pKa of about 16 to 18,
30 including methanol, ethanol, n-propyl alcohol, isopropyl alcohol, n-butyl alcohol, sec-butyl alcohol, isobutyl alcohol, and tert-butyl alcohol is added to the reaction. Of these, tert-butyl alcohol is preferred.

5 Since it has been found that titanocene dichloride and sodium tetrahydridoborate are stable to mildly acidic alcohols such as tert-butanol, polynuclear aromatic compounds can be reduced under relatively mild acidic conditions using the catalyst reagent.

Polynuclear aromatic hydrocarbons reduced by the process include anthracene, phenanthracene, naphthacene, fluorene, pyrene, benzpyrene, chrysene, acenaphthene, and the like.

10 Optionally, an amine is added to the reaction in reducing polynuclear aromatic hydrocarbons. The optionally added amines employed in the reaction are those described previously.

15 The products resulting from the reduction of polynuclear aromatic hydrocarbons include dihydro and tetrahydro species, such as dihydroanthracene and tetrahydronaphthalene.

20 The following examples will serve to further typify the nature of the invention but should not be construed as a limitation on the scope thereof which is defined solely by the appended claims.

Example 1

25 Two hundred fifty milligrams of titanocene dichloride (1.0 mmol), 1.24 grams of sodium tetrahydridoborate (0.033 mmol) and 15 mL of diethylene glycol dimethyl ether are heated in a reaction vessel at 125°C. In a separate reaction vessel, 0.99 grams of azobenzene (0.005 mmol) and 2.63 milliliters of pyridine are dissolved in 10 mL of diethylene glycol dimethyl ether. Thereafter, the separate
30 solutions are combined and heated at 125°C. One milliliter aliquots are quenched with water, extracted with diethyl

ether, purified by passing through a short column of silica gel, and subjected to gas chromatography analysis. The results of the analysis show that reduction to aniline occurs in approximately one hour.

5

Example 2

Two hundred fifty milligrams of titanocene dichloride (1.0 mmol) and 1.24 grams of sodium tetrahydridoborate (0.033 mol) are heated in a reaction vessel at 125°C with fifteen milliliters of diethylene glycol dimethyl ether. In
10 a separate vessel, 1.32 grams of 4-(diethylamino)azobenzene (0.005 mmol) and 2.63 milliliters of pyridine are dissolved in ten milliliters of diethylene glycol dimethyl ether. The two solutions are combined and the resulting reaction mixture is heated at 125°C. One milliliter aliquots are
15 quenched with water, extracted with diethyl ether, purified by passing through a short column of silica gel and subjected to gas chromatography analysis. Reduction of 4-(diethylamino)azobenzene results in a mixture of aniline and 4-(diethylamino)aniline.

20

Example 3

One hundred twenty-five milligrams of titanocene dichloride (0.5 mmol), 0.62 grams of sodium tetrahydridoborate (0.016 mol), 0.50 grams of 1,2-diphenylhydrazine (0.003 mol), and 1.32 mL of pyridine are dissolved in 10 mL of
25 diethylene glycol dimethyl ether and introduced into a reaction vessel. The reaction mixture is heated at 125°C for approximately thirty minutes. One milliliter aliquots are withdrawn and quenched with water, extracted with diethyl ether, purified by passing through a short column of
30 silica gel and analyzed by gas chromatography to show reduction to aniline.

Example 4

Two hundred fifty milligrams of titanocene dichloride (1.0 mmol), 1.24 grams of sodium tetrahydridoborate (0.033

mmol), and fifteen milliliters of diethylene glycol dimethyl ether are introduced into a reaction vessel and heated at 125°C. A solution of 0.98 grams of nitrobenzene (0.008 mmol) and 2.6 mL of pyridine dissolved in 10 mL of diethylene glycol dimethyl ether is added to the mixture. The resulting reaction mixture is heated at 125°C. One milliliter aliquots are quenched with water, extracted with diethyl ether, purified by passing through a short column of silica gel and subjected to gas chromatography analysis. Nitrobenzene was reduced to a mixture of aniline and azobenzene in about 30 minutes. The remaining azobenzene was further reduced to aniline by following the procedure of Example 2.

Example 5

In a suitable reaction vessel, 1.24 grams of sodium borohydride (0.033 mmol) and 15 milliliters of diethylene glycol dimethyl ether are heated at 125°C. In a separate reaction vessel, 0.99 grams of azobenzene (0.005 mmol) and 2.63 milliliters of pyridine are dissolved in 10 mL of diethylene glycol dimethyl ether. The two solutions are combined and heated at 125°C. One milliliter aliquots quenched with water are extracted with diethyl ether and purified by passing through a short column of silica gel. The results of the gas chromatography analysis show that after twenty-four hours, more than 80% of the starting material remains.

Example 6

In a reaction vessel, 26.6 mg of titanocene dichloride (0.107 mmol) and 20.3 mg of sodium tetrahydridoborate (0.537 mmol) are dissolved in 10 mL of diethylene glycol dimethyl ether. A solution of 40 mg of anthracene (0.225 mmol), 0.04 mL of pyridine, and 16.6 mg of tert-butyl alcohol (0.224 mmol) is added. The reaction mixture is heated at 125°C. One milliliter aliquots are hydrolyzed, extracted with diethyl ether, purified by passing through a short column of

silica gel, and analyzed by gas chromatography to show complete conversion to 9,10-dihydroanthracene as the major product, and 1,2- and 1,4-dihydroanthracene as the minor products.

1

2 What is claimed is:

- 3 1. In the process of reducing a nitrogen-containing
4 substituent in an aliphatic or aromatic compound in
5 which said substituent is at an oxidative state higher
6 than that of a primary amine, to a nitrogen-containing
7 substituent having a lower oxidative state, the
8 improvement which comprises treating said compound in
9 the presence of a reagent comprising:
- 10 (i) at least one complex of a transition metal of
11 group 4 or 5 with a multidentate or unidentate organic
12 or inorganic ligand; and
13
- 14 (ii) a reducing agent.
- 15
- 16 2. The method of claim 1 wherein said ligand of said
17 complex is selected from the group consisting of:
18 benzoate, chloride, cyclopentadienide, substituted
19 cyclopentadienide, indenide, substituted indenide,
20 salen, porphyrin, tris(pyrazolyl) borate,
21 poly(alkylamine), or poly(thioalkyl).
- 22 3. The process according to claim 2 wherein the complex is
23 a titanium or zirconium complex.
- 24 4. The process according to claim 3 wherein the reducing
25 agent is a hydridoborate or a polyhydridoborate.
- 26 5. The process according to claim 4 wherein the reducing
27 agent is an alkali metal or metal chelate thereof, or
28 ammonium salt of a tetrahydridoborate, thiocyanatotrihy-
29 dridoborate, cyanotrihydridoborate, acyloxytrihydro-
30 borate, octahydridotrihydridoborate, trialkylhydridobor-
31 ate, acetanilidetrihydridoborate, trialkoxyhydridobor-
32 ate.

- 1 6. The process according to claim 1 wherein the reduction
2 is conducted in the presence of an aliphatic or aromatic
3 amine.
- 4 7. The process according to claim 6 wherein the amine is
5 trimethylamine, triethylamine, dimethylethylamine, N,N-
6 dimethylaniline, N,N-dimethylnaphthylamine, pyridine, 1-
7 methylimidazole, quinoline, or piperidine.
- 8 8. The process according to claim 6 wherein the reduction
9 is conducted in the presence of an inert organic
10 solvent.
- 11 9. The process according to claim 8 wherein the inert
12 organic solvent is diglyme, triglyme, *bis*-(2-ethoxyeth-
13 yl)ether, tetrahydrofuran, dimethylsulfoxide, or ethyl-
14 ene glycol dimethyl ether.
- 15 10. The process according to claim 1 wherein the complex is
16 *bis*-(η^5 -cyclopentadienyl)titanium dichloride and the
17 reducing agent is sodium tetrahydridoborate.
- 18 11. The process according to claim 1 wherein the aliphatic
19 or aromatic compounds are trinitrotoluene, trinitro-
20 phenol, glyceryl nitrate, 1,3,5,7-tetranitrooctahydro-
21 1,3,5,7-tetrazocine, or hexahydro-1,3,5-trinitro-1,3,5-
22 triazine.
- 23 12. In the process of reducing at least one double bond in
24 polynuclear aromatic hydrocarbon compounds from a higher
25 oxidative state to a lower oxidative state, the
26 improvement which comprises reducing said compound in
27 the presence of a reagent comprising:
- 28 (i) at least one complex of a transition metal of group
29 4 or 5 with a multidentate or unidentate organic or
30 inorganic ligand; and
31 (ii) a reducing agent.

- 1 13. The method of claim 12 wherein said ligand of said
2 complex is selected from the group consisting of:
3 benzoate, chloride, cyclopentadienide, substituted
4 cyclopentadienide, indenide, substituted indenide,
5 salen, porphyrin, tris(pyrazolyl) borate, poly(alkyla-
6 mine), or poly(thio-alkyl).
7
- 8 14. The process according to claim 13 wherein the complex is
9 a titanium or zirconium complex.
- 10 15. The process according to claim 14 wherein the reducing
11 agent is a hydridoborate or polyhydridoborate.
- 12 16. The process according to claim 15 wherein the reducing
13 agent is an alkali metal or metal chelate thereof, or
14 ammonium salt of a tetrahydridoborate, thiocyanatotrihy-
15 dridoborate, cyanotrihydridoborate, acyloxytrihydro-
16 borate, octahydridotrihydridoborate, trialkylhydridobor-
17 ate, acetanilidetrihydridoborate, trialkoxyhydridobor-
18 ate, and metal chelates thereof.
- 19 17. The process according to claim 12 wherein the reduction
20 is conducted in the presence of an aliphatic or aromatic
21 amine.
- 22 18. The process according to claim 17 wherein the added
23 amine is trimethylamine, triethylamine, dimethyléthyl-
24 amine, N,N-dimethylaniline, N,N-dimethylnaphthylamine,
25 pyridine, 1-methylimidazole, quinoline, or piperidine.
- 26 19. The process according to claim 17 wherein the reduction
27 is conducted in the presence of an inert organic
28 solvent.
- 29 20. The process according to claim 19 wherein the inert
30 organic solvent is diglyme, triglyme, bis-(2-ethoxyeth-
31 yl)ether, tetrahydrofuran, dimethylsulfoxide, or ethyl-
32 ene glycol dimethyl ether.

- 1 21. The process according to claim 12 wherein the complex is
2 *bis*-(η^5 -cyclopentadienyl)titanium dichloride and the
3 reducing agent is sodium tetrahydridoborate.
- 4 22. The process according to claim 12 wherein the
5 polynuclear aromatic hydrocarbon compounds are anthra-
6 cene, phenanthracene, fluorene, pyrene, benzpyrene,
7 chrysene, acenaphthene, or naphthacene.
- 8 23. The process according to claim 12 wherein the reaction
9 is conducted in the presence of an alcohol.
- 10 24. The process according to claim 23 wherein the alcohol is
11 *tert*-butanol.

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER
 IPC(6) :C07C 209/68; C07F 5/02
 US CL :564/305, 415; 568/01; 548/335.1; 546/152, 184
 According to International Patent Classification (IPC) or to both national classification and IPC

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 Minimum documentation searched (classification system followed by classification symbols)
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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)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A, P	US 5,504,253 A (VANWAGENEN ET AL.) 02 April 1996 (02.04.96), see entire document.	1-24

Further documents are listed in the continuation of Box C. See patent family annex.

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Date of the actual completion of the international search 11 SEPTEMBER 1996	Date of mailing of the international search report 27 SEP 1996
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