

PROCESSES FOR THE PREPARATION OF DOUBLE METAL CYANIDE (DMC) CATALYSTS

FIELD OF THE INVENTION

The present invention relates in general to processes for making double metal cyanide (DMC) catalysts, and more particularly, to processes for preparing substantially amorphous DMC catalysts at low molar ratios of transition metal salt to cyanide metal salt by simultaneously controlling the alkalinity of the metal salt used to make the catalyst, the molar ratio of water to total cations, the molar ratio of ligand to transition metal cation, and/or the molar ratio of metal salt anion to metal cyanide anion.

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BACKGROUND OF THE INVENTION

Double metal cyanide (DMC) complexes are well known to those skilled in the art for catalyzing epoxide polymerization. Double metal cyanide (DMC) catalysts for the polyaddition of alkylene oxides to starter compounds, which have active hydrogen atoms, are described, for example, in U.S. Pat. No's. 3,404,109, 3,829,505, 3,941,849 and 5,158,922. These active catalysts yield polyether polyols that have low unsaturation compared to similar polyols made with basic (KOH) catalysis. DMC catalysts can be used to make many polymer products, including polyether, polyester, and polyetherester polyols. The polyether polyols obtained with DMC catalysts can be processed to form high-grade polyurethanes (e.g., coatings, adhesives, sealants, elastomers and foams).

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DMC catalysts are usually prepared by the reaction of an aqueous solution of a metal salt with an aqueous solution of a metal cyanide salt in the presence of an organic complexing ligand such as, for example, an ether. In a typical catalyst preparation, aqueous solutions of zinc chloride (in excess) and potassium hexacyanocobaltate are mixed, and

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dimethoxyethane (glyme) is subsequently added to the formed suspension. After filtration and washing of the catalyst with aqueous glyme solution, an active catalyst of formula:



is obtained.

DMC catalysts prepared in this way have a relatively high degree of crystallinity. Such catalysts are used for making epoxide polymers. The activity for epoxide polymerization, which exceeds the activity available from the commercial standard (KOH), was at one time thought to be adequate. Later, it became apparent that more active catalysts would be important for the successful commercialization of polyols from DMC catalysts.

15 Highly active DMC catalysts are typically substantially non-crystalline, as is evidenced by powder X-ray diffraction patterns that lack many sharp lines. The catalysts are active enough to allow their use at very low concentrations, often low enough to overcome any need to remove the catalyst from the polyol.

20 Hinney et al., in U.S. Pat. No. 5,158,922, disclose that at least a 100% excess of transition metal salt is needed to prepare highly active double metal cyanide (DMC) catalysts. For a double metal cyanide compound such as zinc hexacyanocobaltate with the chemical formula $\text{Zn}_3[\text{Co}(\text{CN})_6]_2$, the use of 3.0 moles of transition metal cation per mole of metal cyanide anion in the catalyst preparation provides a 100% excess.

25 As those skilled in the art may be aware, significant drawbacks can be encountered in using 100% more than the stoichiometric requirement of metal salt. Such disadvantages include greatly increasing the cost of catalyst production and increasing the likelihood of operator exposure to hazardous materials and/or equipment corrosion. Nevertheless, the previously described processes for preparation of highly active substantially amorphous DMC catalysts employ at least 3.0 moles of

transition metal cation per mole of metal cyanide anion. For example, U.S. Pat. No. 5,470,813, issued to Le-Khac, describes substantially amorphous or non-crystalline catalysts that have much higher activities compared with earlier DMC catalysts. The DMC catalysts made according to the methods
5 of Le-Khac '813 can have transition metal cation to metal cyanide molar ratios of approximately 25. Other highly active DMC catalysts include, in addition to a low molecular weight organic complexing agent, from about 5 to about 80 wt. % of a polyether such as a polyoxypropylene polyol (see U.S. Pat. Nos. 5,482,908 and 5,545,601).

10 U.S. Pat. No. 5,627,122, issued to Le-Khac et al., describes substantially crystalline, highly active, double metal cyanide (DMC) complex catalysts. The catalysts contain less than about 0.2 moles of metal salt per mole of DMC compound in the catalyst.

Combs et al., in U.S. Pat. No. 5,783,513, describe very active,
15 amorphous double metal cyanide (DMC) catalysts with improved performance, which is attributed to the use of basic compounds that control alkalinity of the reaction system. Desirable alkalinities are taught to range only from 0.20% to 2.0% based on the amount of transition metal salt used in the reaction. Alternatively, those alkalinities, when expressed
20 as moles of alkaline metal compound per mole of transition metal salt, range from 0.0033 to 0.0324. The catalysts of Combs et al. may readily be identified by the presence of a peak in the infrared spectrum at approximately 642 cm^{-1} . The catalyst-making procedures taught require mixing aqueous solutions of zinc chloride and potassium
25 hexacyanocobaltate in the presence of organic complexing agents such as tert-butyl alcohol (TBA).

U.S. Pat No. 6,696,383, issued to Le-Khac et al., teaches the addition of alkali metal salts during the preparation of DMC catalysts to enhance activity and reduce formation of small amounts of very high
30 molecular weight polyol impurities.

None of the above-referenced art provides a means to reduce the amount of metal salt in the catalyst producing process to less than a 100% excess of transition metal salt. That is, more than 3.0 moles of transition metal cation are used per mole of metal cyanide anion. Several workers
5 have attempted to find ways around this requirement.

One solution is described in U.S. Pat. No. 5,952,261, issued to Combs, in which cyanide-free Group IIA alkaline earth metal salts are used in combination with a stoichiometric amount (or less) of transition metal salt to prepare active double metal cyanide (DMC) catalysts.
10 Combs '261 also discloses in its experimental examples use of alkaline metal compounds at levels of 0.079 to 0.15 moles of alkaline metal compound per mole of transition metal salt corresponding to about 5% to 10% alkalinity expressed as metal oxide based on metal salt. However, the '261 patent is silent as to whether the catalyst is crystalline or
15 amorphous.

Eleveld et al., in U.S. Pat. No 6,716,788 describe a process for making double metal cyanide catalysts where even higher alkalinity metal salt is disclosed. Alkalinities ranging from 0.03 to 0.08 moles of alkaline metal salt to transition metal salt are used in experimental examples
20 although the claims recite levels as high as 0.4 moles. It is noted that all examples in the '788 patent employ more than 3.0 moles of transition metal cation per mole of metal cyanide anion.

Thus, neither the Combs '261 patent nor the '788 patent provides any framework or guidance as to specific adjustment of molar ratios of
25 water to ionic species, or molar ratios of ligand to transition metal cation, in order to prepare highly active amorphous DMC catalysts with less than 100% excess of metal salt. As those skilled in the art are aware, even the best double metal cyanide (DMC) catalysts can be improved. Less expensive catalysts with increased activity always remain a desired goal.
30 Therefore, a need always exists in the art for processes for producing

double metal cyanide (DMC) catalysts that require a much lower amount of transition metal salt, but which still provide catalysts with the sought after high activity.

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SUMMARY OF THE INVENTION

Accordingly, the present invention provides such processes in which highly active, substantially amorphous double metal cyanide (DMC) catalysts can be prepared with very low mole ratios of metal salt to mole of cyanide salt metal by simultaneously controlling the alkalinity of the transition metal salt, the molar ratio of water to total cations, the molar ratio of ligand to transition metal cation, the molar ratio of metal salt anion to metal cyanide anion, and the presence of a polymeric complexing ligand during the catalyst precipitation step.

The inventive processes yield DMC catalysts that are substantially amorphous and which exhibit a characteristic peak in the infrared spectrum in the range of about 600-650 cm^{-1} . The DMC catalysts produced by the inventive processes can be used to produce polyether polyols, which in turn can be processed to form high-grade polyurethanes.

These and other advantages and benefits of the present invention will be apparent from the Detailed Description of the Invention herein below.

BRIEF DESCRIPTION OF THE FIGURES

The present invention will now be described for purposes of illustration and not limitation in conjunction with the figures, wherein:

Figure 1 shows the X-ray diffraction pattern of the comparative DMC catalysts and one DMC catalyst made by the inventive process;

Figure 2 illustrates the X-ray diffraction pattern of the DMC catalyst prepared by the inventive process according to Example 7; and

Figure 3 depicts the X-ray diffraction pattern of the DMC catalyst prepared by the inventive process according to Example 8.

DETAILED DESCRIPTION OF THE INVENTION

The present invention will now be described for purposes of illustration and not limitation. Except in the operating examples, or where otherwise indicated, all numbers expressing quantities, percentages, OH numbers, functionalities and so forth in the specification are to be understood as being modified in all instances by the term "about." Equivalent weights and molecular weights given herein in Daltons (Da) are number average equivalent weights and number average molecular weights respectively, unless indicated otherwise.

The present inventors have surprisingly found that processes for the preparation of double metal cyanide catalysts using less than 100% excess of metal salt are possible by:

1. using alkali metal salts which are free of cyanide;
2. using optimal concentrations of reactants where the mole ratio of cyanide-free anion to hexacyanometallate anion is less than about 6 and the mole ratio of water to total cations is less than about 200; and
3. using functionalized polymeric ligands where the mole ratio of water to cations is greater than about 100 and the mole ratio of cyanide-free anion to metal cyanide anion is less than about 6.

Without wishing to be bound by any theory, the inventors herein speculate that properly manipulating these process parameters promotes formation of soluble, complexed cationic species involving the transition metal cation and anion such that they are readily incorporated into the catalyst matrix.

All of the inventive processes provide for the preparation of highly active, substantially amorphous double metal cyanide (DMC) catalysts, by reacting, in aqueous solution, a transition metal salt having an alkalinity of at least 2 wt. %, with a metal cyanide salt such that the molar ratio of transition metal cation to metal cyanide anion is less than 2.9:1, more preferably less than 2.5:1 and most preferably less than 1.5:1. The alkalinity is expressed as weight percent transition metal oxide based on the amount of transition metal salt. The reaction step is understood herein

to be the act of mixing the metal salt and the metal cyanide salt to produce a precipitated solid. In some embodiments of the present invention, the reaction step takes place in the presence of an organic complexing ligand.

In one embodiment of the present invention, a cyanide-free
5 compound (i.e., an anion and an alkali metal) is added in the reaction step to maintain a minimum mole ratio of cyanide-free anion to metal cyanide anion above 3 and the mole ratio of water to total cations is less than 150. "Total cations" include those from the alkali metal salt and the transition metal salt. More preferably, the mole ratio of water to cations is less than
10 75 and the mole ratio of cyanide-free anion to metal cyanide anion is above 6. The alkali metal salt anion may be the same as or different from the transition metal salt anion. Also the amount of complexing organic ligand used in the reaction step is greater than about 1 mole of ligand per mole of transition metal salt, more preferably greater than about 5. The
15 precipitated solid may or may not be treated with a functionalized polyether after the reaction step.

In another embodiment, the present invention involves a process where the mole ratio of cyanide-free anion to metal cyanide anion is between 3 and 6 and the mole ratio of water to total cations is less than
20 250. More preferably, the mole ratio of water to total cations is less than 200. To promote retention of the metal salt in the catalyst, sufficient ligand must be used to obtain a ligand to transition metal salt cation mole ratio greater than 5. More preferably, the mole ratio of ligand to metal salt cation is greater than 10 and most preferably between 10 and 200. As a
25 general rule, the inventors herein have found that higher ratios of water to cation require higher ratios of ligand to metal salt cation. The precipitated solid may or may not be treated with a functionalized polyether after the reaction step.

In yet another embodiment of the present invention, the catalyst
30 may be prepared in very dilute solution, the mole ratio of cyanide-free anion to metal cyanide anion is greater than 3 and less than 6, the mole ratio of water to total cations is greater than 100, and functionalized

polymeric complexing agents are used with or without typical low molecular weight complexing ligand(s) in the reaction step. More preferably, the mole ratio of water to total cations is greater than 150 and most preferably between 150 and 500. To prepare substantially
5 amorphous, highly active catalysts at high dilutions in aqueous systems, it is desirable but not required that the functionalized polymeric ligand be soluble in the reaction system. The polymeric complexing ligands are more efficient than simple complexing ligands at promoting retention of metal salt in reaction systems with high water to total cation ratios. The
10 mole ratio of polymeric complexing ligand to transition metal cation may be less than 10 and more preferably is less than 1 even where the water to total cation ratio is greater than 200.

All of the inventive processes produce substantially amorphous, highly active, double metal cyanide (DMC) catalysts with a characteristic
15 peak in the range of about 600 to 650 cm^{-1} as described in copending U.S. patent application Serial No. 10/649,520. It will also become apparent that different features of the inventive processes may be combined with each other in various ways. For example, an alkali metal salt may be used in more dilute solutions where the mole ratio of cyanide-free anion to metal
20 cyanide anion is less than about 6.

Transition metal salt

The transition metal salt used in the processes of the present invention preferably is water soluble and has the formula (I),
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in which M is chosen from Zn(II), Fe(II), Ni(II), Mn(II), Co(II), Sn(II), Pb(II), Fe(III), Mo(IV), Mo(VI), Al(III), V(V), V(IV), Sr(II), W(IV), W(VI), Cu(II), and Cr(III). More preferably, M may be chosen from Zn(II), Fe(II), Co(II), and
30 Ni(II).

In the above formula (I), X is preferably an anion chosen from halides, hydroxides, sulfates, carbonates, cyanides, oxalates, thiocyanates, isocyanates, isothiocyanates, carboxylates, and nitrates.

The value of n is from 1 to 3 and satisfies the valency state of M.

5 Examples of suitable transition metal salts include, but are not limited to, zinc chloride, zinc bromide, zinc acetate, zinc acetylacetonate, zinc benzoate, zinc nitrate, iron(II) sulfate, iron(II) bromide, cobalt(II) chloride, cobalt(II) thiocyanate, nickel(II) formate, nickel(II) nitrate, and the like, and mixtures thereof; with zinc chloride being the most preferred.

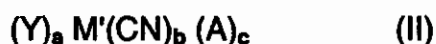
10 As mentioned hereinabove, the alkalinity of the transition metal salt used in the inventive process is one of the variables to be controlled. In the inventive processes, aqueous solutions of the transition metal salt preferably have an alkalinity of greater than 2.0 wt. % as metal oxide based on the amount of metal salt. For example, if the transition metal salt
15 used is zinc chloride (commonly used to make zinc hexacyanocobaltate), the alkalinity of aqueous zinc chloride used in the process preferably may range from 2.1 to 20 wt. % as zinc oxide based on the amount of zinc chloride in the solution. A more preferred range for the transition metal salt is 2.8 to 15 wt. % as transition metal oxide; most preferred is the range
20 from 3.0 to 12 wt. % as transition metal oxide. The alkalinity of the transition metal may be in an amount ranging between any combination of these values, inclusive of the recited values.

 The alkalinity of the transition metal salt often depends on the source of the metal salt. Technical-grade transition metal salts, e.g.,
25 technical-grade zinc chloride, are particularly preferred in large-scale catalyst preparations because of the relatively lower cost. However, technical-grade transition metal salts often contain acidic impurities, and aqueous solutions of these salts can have extremely low alkalinities (less than 0.2 wt. % as metal oxide). For example, the inventors herein have
30 found that technical grade zinc chloride solutions normally have alkalinities within the range of 0 to 0.3 wt. % as zinc oxide. In such instances, the inventors herein have added a base to the aqueous solution to adjust the

alkalinity to a value of more than 2.0 wt. % as metal oxide. Suitable bases are compounds that when added to pure water result in a solution having a pH greater than 7.0. The base may be an inorganic base, such as a metal oxide, an alkali metal hydroxide, or an alkali metal carbonate, or an organic base, such as an amine. The basic compound may be added to the metal salt solution or the metal cyanide salt solution prior to or during mixing of the reagents in the reaction step.

Metal cyanide salt

- 10 The metal cyanide salt reacted in the inventive processes preferably is water soluble and has the formula (II),



- in which M' is chosen from Fe(II), Fe(III), Co(II), Co(III), Cr(II), Cr(III), Mn(II), Mn(III), Ir(III), Ni(II), Rh(III), Ru(II), V(IV), and V(V). More preferably, M' is chosen from Co(II), Co(III), Fe(II), Fe(III), Cr(II), Ir(III), and Ni(II). The metal cyanide salt may contain one or more of these metals.

- In the above formula (II), Y is hydrogen, an alkali metal ion, or alkaline earth metal ion. A is an anion chosen from halides, hydroxides, sulfates, carbonates, cyanides, oxalates, thiocyanates, isocyanates, isothiocyanates, carboxylates, and nitrates. Both a and b are integers greater than or equal to 1; and the sum of the charges of a, b, and c balances the charge of M'. Suitable metal cyanide salts include, but are not limited to, potassium hexacyanocobaltate(III), potassium hexacyanoferrate(II), potassium hexacyanoferrate(III), calcium hexacyanocobaltate(III), lithium hexacyanoiridate(III), and the like. Alkali metal hexacyanocobaltates are most preferred.

- Examples of double metal cyanide compounds that can be made by the process of the present invention include, but are not limited to, zinc hexacyanocobaltate(III), zinc hexacyanoferrate(III), zinc hexacyanoferrate(II), nickel(II) hexacyanoferrate(II), cobalt(II) hexacyanocobaltate(III), and the like; with zinc hexacyanocobaltate(III) being the most preferred.

Cyanide-free compound

Some of the inventive processes occur in the presence of a cyanide-free alkali metal containing compound. This alkali metal containing compound is included to maintain the molar ratio of metal salt anion to metal cyanide anion. Of the alkali metals, particularly preferred are lithium, sodium, potassium, and cesium. The cyanide free compound preferably has an anion chosen from halides, hydroxides, sulfates, carbonates, oxalates, carboxylates and nitrates. Sodium and potassium salts are most preferred.

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Organic complexing agent

The inventive processes may occur in the presence of an organic complexing agent, i.e., the complexing agent may be added either during preparation or immediately following precipitation of the catalyst. An excess amount of the complexing agent is preferably used and the complexing agent is preferably relatively soluble in water. Suitable complexing agents are those commonly known in the art, as taught, for example, in U.S. Pat. No. 5,158,922, the entire contents of which are incorporated herein by reference thereto. Preferred complexing agents are water-soluble heteroatom-containing organic compounds that can complex with the double metal cyanide compound. Suitable complexing agents include, but are not limited to, alcohols, aldehydes, ketones, ethers, esters, amides, ureas, nitrites, sulfides, and mixtures thereof. Preferred complexing agents are water-soluble aliphatic alcohols chosen from ethanol, isopropyl alcohol, n-butyl alcohol, isobutyl alcohol, sec-butyl alcohol, 2-methyl-3-butene-2-ol, 2-methyl-3-butenyl-2-ol, and tert-butyl alcohol. Tert-butyl alcohol is most preferred.

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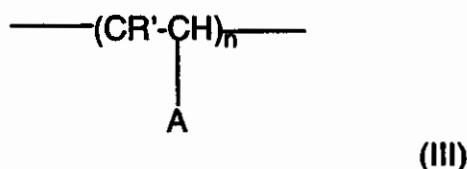
Catalysts made by the processes of the present invention are substantially amorphous (non-crystalline). By "substantially amorphous," the inventors herein mean that the catalyst is lacking a well-defined crystal structure, or characterized by the substantial absence of sharp lines in the powder X-ray diffraction pattern of the composition. Conventional zinc

hexacyanocobaltate-glyme catalysts (such as those described in U.S. Pat. No. 5,158,922) show a powder X-ray diffraction pattern containing many sharp lines, indicative of a high degree of crystallinity. Zinc hexacyanocobaltate prepared in the absence of a complexing agent is highly crystalline and is inactive for epoxide polymerization. Catalysts made by the inventive process are substantially amorphous and highly active.

Functionalized Polymer

DMC catalysts produced by the processes of the present invention may optionally include a functionalized polymer or its water-soluble salt. By "functionalized polymer" the inventors herein mean a polymer that contains one or more functional groups containing oxygen, nitrogen, sulfur, phosphorus, or halogen, wherein the polymer, or a water-soluble salt derived from it, has relatively good solubility in polar solvents, i.e., at least 0.5 wt. % of the polymer or its salt dissolves at room temperature in water or mixtures of water with a water-miscible organic solvent. Examples of water-miscible organic solvents include, but are not limited to, tetrahydrofuran, acetone, acetonitrile, tert-butyl alcohol, and the like. Water solubility is important for incorporating the functionalized polymer into the catalyst structure during formation and precipitation of the double metal cyanide compound.

Preferred functionalized polymers are represented by the formula (III),



in which R' is hydrogen, ---COOH , or a $\text{C}_1\text{---C}_5$ alkyl group, and A is one or more functional groups chosen from ---OH , ---NH_2 , ---NHR , ---NR_2 , ---SH , ---SR , ---COR , ---CN , ---C , ---Br , $\text{---C}_6\text{H}_4\text{---OH}$, $\text{---C}_6\text{H}_4\text{---C}(\text{CH}_3)_2\text{OH}$, ---CONH_2 , ---CONHR , ---CO---NR_2 , ---OR , ---NO_2 , ---NHCOR , ---NRCOR , ---COOH , ---COOR , ---CHO , ---OCOR , ---COO---R---OH , $\text{---SO}_3\text{H}$, $\text{---CONH---R---SO}_3\text{H}$,

pyridinyl, and pyrrolidonyl, in which R is a C₁-C₅ alkyl or alkylene group, and n has a value within the range of 5 to 5,000. More preferably, n is within the range of 10 to 500.

5 The molecular weight of the functionalized polymer can vary over a fairly wide range. Preferably, the number average molecular weight is within the range of 200 to 500,000; more preferably from 500 to 50,000. The molecular weight of the functionalized polymer may be in an amount ranging between any combination of these values, inclusive of the recited values.

10 Optionally, the functionalized polymer also includes recurring units derived from a non-functionalized vinyl monomer such as an olefin or diene, e.g., ethylene, propylene, butylenes, butadiene, isoprene, styrene, or the like, provided that the polymer or a salt derived from it has relatively good solubility in water or mixtures of water and a water-miscible organic
15 solvent.

Suitable functionalized polymers include, but are not limited to, poly(acrylamide), poly(acrylamide-co-acrylic acid), poly(acrylic acid), poly(2-5 acrylamido-2-methyl-1-propanesulfonic acid), poly(acrylic acid-co-maleic acid), poly(acrylonitrile), poly(alkyl acrylate)s, poly(alkyl
20 methacrylate)s, poly(vinyl methyl ether), poly(vinyl ethyl ether), poly(vinyl acetate), poly(vinyl alcohol), poly(N-vinylpyrrolidone), poly(N-vinylpyrrolidone-co-acrylic acid), poly(N,N-dimethylacrylamide), poly(vinyl methyl ketone), poly(4-vinylphenol), poly(4-vinylpyridine), poly(vinyl chloride), poly(acrylic acid-co-styrene), poly(vinyl sulfate), poly(vinyl
25 sulfate) sodium salt, and the like.

Preferred functionalized polymers are polyethers, particularly preferred are polyether polyols. Suitable polyethers for use in the processes of the present invention include polyethers produced by ring-opening polymerization of cyclic ethers, and epoxide polymers, oxetane
30 polymers, tetrahydrofuran polymers, and the like. Any method of catalysis may be used to make the polyethers. The polyethers can have any desired end groups, including, for example, hydroxyl, amine, ester, ether,

or the like. Preferred polyethers are polyether polyols having average hydroxyl functionalities from 1 to 8 and number average molecular weights within the range of 200 to 10,000, more preferably from 500 to 5000.

These are usually made by polymerizing epoxides in the presence of
5 active hydrogen-containing initiators and basic, acidic, or organometallic catalysts (including DMC catalysts). Useful polyether polyols include poly(oxypropylene) polyols, poly(oxyethylene) polyols, EO-capped poly(oxypropylene) polyols, mixed EO-PO polyols, butylene oxide
10 polymers, butylene oxide copolymers with ethylene oxide and/or propylene oxide, polytetramethylene ether glycols, and the like. Most preferred are poly(oxypropylene) polyols and mixed EO-PO polyols, particularly monols and diols having number average molecular weights within the range of 500 to 4000.

Other functionalized polymers may include polycarbonates,
15 oxazoline polymers, polyalkylenimines, maleic acid and maleic anhydride copolymers, hydroxyethyl cellulose, starches, and polyacetals. Thus, the functionalized polymer may be, for example, poly(ethylene glycol adipate), poly(dipropylene glycol adipate), poly(1,6-hexanediol carbonate), poly(2-ethyl-2-oxazoline), poly(vinyl butyral-co-vinyl alcohol-co-vinyl acetate), and
20 the like, and salts thereof.

Catalysts made by the processes of the present invention optionally contain up to 80 wt. % (based on the total amount of catalyst) of the functionalized polymer. More preferably, the catalysts contain from 5 to 70 wt. % of the polymer; most preferred is the range from 10 to 60 wt. %. At
25 least 2 wt. % of the polymer is needed to significantly improve the catalyst activity compared with a catalyst made in the absence of the polymer. Catalysts that contain more than 80 wt. % of the polymer are generally no more active, and are often difficult to isolate. The functionalized polymer may be present in the catalyst in an amount ranging between any
30 combination of these values, inclusive of the recited values.

Alternatively, the functionalized polymer may be partially or completely replaced with complex organic ligands such as those described for example in U.S. Pat. Nos. 6,204,357, 6,391,820, 6,468,939, 6,528,616, 6,586,564, 6,586,566 and 6,608,231.

5 Substantially amorphous catalysts produced by the processes of the present invention may take the form of powders or pastes. Preferred paste catalysts contain from 10 to 60 wt. % of a double metal cyanide compound, from 40 to 90 wt. % of an organic complexing agent, and from 1 to 20 wt. % of water. In preferred paste catalysts, at least 90% of the
10 catalyst particles have a particle size less than 10 microns as measured by light scattering in polyether polyol dispersions of the catalyst particles. Paste catalysts and methods for making them are fully described in U.S. Pat. No. 5,639,705, the entire contents of which are incorporated herein by reference thereto.

15 Catalysts produced by the processes of the present invention have unique infrared spectra that result from the use of metal salts with relatively high alkalinity. The catalysts have a unique peak in the range of 600 to 650 cm^{-1} as detailed in copending U.S. patent application Serial No. 10/649,520. Preferably, the intensity of this peak increases as the
20 alkalinity of the metal salt solution used in making the catalyst increases.

Reactors and processing conditions

The catalysts made by the processes of the present invention are useful in any reactor configuration that can be used to prepare polyethers
25 or polyether-ester polyols. The semibatch process is widely used and these reactors could utilize a range of mixing conditions with energy inputs from 0.5 to 20 horsepower per 1000 gallons with mixing energies of 5 to 8 hp/1000 gallons proving particularly useful. Those skilled in the art will appreciate that the optimum energy input will likely vary with the product
30 molecular weight, e.g., a greater amount of energy is preferred for

products with higher viscosities. Other process conditions, which may be useful, include purging the reactor oxide-feed tube or pipe with nitrogen or another inert fluid or gas after completion of the oxide feed.

The DMC catalysts produced by the processes of the present invention will also likely be particularly useful in a continuous reactor used to produce polyethers. For example, the catalyst can be charged to the reactors as a slurry in polyether, such as a 700 Da diol. In such instances, it may be particularly desirable to use a high-shear mixer or similar device to create a suspension with a low tendency to settle while it is in the catalyst charge vessel.

The inventors herein have found that DMC catalysts, including those produced by the inventive processes, may appear to be inactive when initially charged to a starter such as a 700 Da propoxylated triol. The rate of activation of the catalyst can be influenced by applying vacuum to the reactor with or without a nitrogen purge and by increasing the concentration of oxide added to the reactor after the stripping procedure is complete. There also can be an advantage to using a lower temperature for activation (e.g. 105°C) and completing the major part of the alkoxylation at a higher temperature (e.g. 130°C).

In polyol production processes designed to operate at low DMC catalyst levels, the quality of propylene oxide and ethylene oxide can be important in obtaining a stable process and in producing a final product with low amounts of contaminants. Low levels of alkalinity or water in the propylene oxide can potentially inhibit or deactivate the catalyst, thereby resulting in high propylene oxide concentrations in the reactors and creating a safety hazard. The permissible water and alkalinity ranges are dependent on the catalyst level. For systems designed to operate at DMC catalyst levels in the range of 20 to 30 ppm, an alkalinity of less than 3 ppm as potassium hydroxide is preferred. The limiting values for alkalinity and water content will vary depending on the molecular weight of the polyol with these parameters being more important with low molecular weight polyols. In processes operating near the process limits, water

levels in the range of several hundred ppm to a thousand ppm can affect process stability. The limiting values of these components may also be related to process type with the continuous process and the semibatch process with the continuous addition of a low molecular weight starter
5 being more sensitive than a conventional semibatch process.

The organic components in the ethylene oxide and propylene oxide are less important for process stability; however, the presence of these materials can affect product quality. Propylene oxide can contain high molecular weight polypropylene oxide that can affect foaming process as
10 these materials are converted to polyurethane. It may be necessary to use a carbon treatment or other process to remove the polypropylene oxide. Low molecular weight components like propionaldehyde, methyl formate, methyl propylether, methyl isopropylether, acetaldehyde, and furan may require an additional polyol process step to remove these
15 components prior to foam manufacture.

EXAMPLES

The present invention is further illustrated, but is not to be limited, by the following examples.

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Comparative Example 1

A DMC catalyst was made according to U.S. Pat. No. 5,783,513 as follows: a one-liter baffled, round-bottom flask was equipped with a mechanical paddle stirrer, heating mantle and a thermometer. Distilled
25 water (275 g) was added to the flask followed by technical grade zinc chloride (76 g). Sufficient zinc oxide was added to bring the alkalinity of the system to 0.48% ZnO. The mixture was stirred at 400 rpm and heated to 50°C until the entire solid dissolved. Tert-butyl alcohol (40.0 g) was added to the solution and the temperature was maintained at 50°C.

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A second solution was prepared with potassium hexacyano-cobaltate (7.4 g) in distilled water (100 g). This potassium hexacyano-cobaltate solution was added to the zinc chloride solution over one hour.

After the addition was completed, stirring was continued for an additional 60 minutes at 50°C. A third solution of 1000 Da diol (7.9 g), tert-butyl alcohol (27.1 g), and water (14.9 g) was prepared and added to the flask at the end of the 60 minute period. The flask contents were stirred for an additional three minutes before the solid wet cake was collected by filtration.

The filter cake was resuspended in a beaker with 70/30 (w/w) tert-butyl alcohol/distilled water solution (100 g) using a homogenizer. The suspended slurry was transferred back to the initial reaction vessel and the beaker was rinsed with 70/30 (w/w) TBA/water solution (56 g) to transfer all of the material. The slurry was stirred for 60 minutes at 400 rpm and 50°C. A 1000 Da diol (2.0 g) was added to the flask and the slurry was stirred for three minutes. The mixture was filtered and the filter cake was resuspended in a beaker with the tert-butyl alcohol solution (100 g) using a homogenizer. The suspended slurry was transferred back to the initial reaction vessel and the beaker was rinsed with tert-butanol (44 g) to transfer all material. The slurry was stirred for 60 minutes at 400 rpm and 50°C. Then, a 1000 Da diol (1.0 g) was added and the mixture was stirred for three more minutes. The slurry was filtered and the solids were collected to dry in a vacuum oven overnight at 40°C to 50°C.

The final yield was 10.5 g of dry powder with the following percentages determined by elemental analysis: Zn = 23.5%; Co = 10.1%; and Cl = 4.3%.

Comparative Example 2

A DMC catalyst was made without the addition of NaCl to maintain the molar ratio of metal salt anion to metal cyanide anion as follows: a one-liter baffled, round-bottom flask was equipped with a mechanical paddle stirrer, heating mantle and a thermometer. Distilled water (275 g) was added to the flask followed by technical grade zinc chloride (6.07 g). Tert-butyl alcohol (40.0 g) was added and the solution was heated to 50°C with stirring at 400 rpm.

A second solution was prepared with potassium hexacyano-cobaltate (7.4 g) in distilled water (100 g). This potassium hexacyano-cobaltate solution was added to the zinc chloride solution over one hour. After the addition was completed, stirring was continued for an additional
5 60 minutes at 50°C. A third solution of 1000 Da -diol (7.9 g), tert-butyl alcohol (27.1 g), and water (14.9 g) was prepared and added to the flask at the end of the 60 minute period. The flask contents were stirred for an additional three minutes before the solid wet cake was collected by filtration.

10 The filter cake was resuspended in the reaction vessel with 70/30 (w/w) tert-butyl alcohol/distilled water solution (156 g). The suspended slurry was stirred for 60 minutes at 400 rpm and 50°C. A 1000 Da diol (2.0 g) was added to the flask and the slurry was stirred for three minutes. The mixture was filtered and the filter cake was resuspended in the
15 reaction vessel with tert-butyl alcohol (144 g). The slurry was stirred for 60 minutes at 400 rpm and 50°C. Then, a 1000 Da diol (1.0 g) was added and the mixture was stirred for three more minutes. The slurry was filtered and the solids were collected to dry in a vacuum oven overnight at 40°C to 50°C.

20 The final yield was 8.8 g of dry powder with the following percentages determined by elemental analysis: Zn = 24.6%; Co = 13.9%; and Cl = 0.8%.

Example 3

25 A DMC catalyst was made at a 2:2 Zn/Co mole ratio with NaCl added to maintain the molar ratio of metal salt anion to metal cyanide anion as follows: a one-liter baffled round bottom flask was equipped with a mechanical paddle stirrer, heating mantle, and a thermometer. Deionized water (275 g) was added to the flask followed by technical

grade zinc chloride (6.07 g) and sodium chloride (60.0 g). Sufficient zinc oxide was added to bring the alkalinity of the system to 6.48% ZnO. Then, tert-butyl alcohol (40.0 g) was added and the solution was heated to 50°C with stirring at 400 rpm.

5 A second solution was prepared with potassium hexacyano-cobaltate (7.4 g) in deionized water (100 g). The potassium hexacyano-cobaltate solution was added to the zinc chloride solution over a one hour period. After addition was complete, stirring was continued for an additional 60 minutes at 50°C. A third solution of 1000 Da diol (7.9 g),
10 tert-butyl alcohol (27.1 g), and water (14.9 g) was prepared and added to the flask at the end of the 60 minute period. The flask contents were stirred for an additional three minutes before collecting the solid wet cake by filtration.

 The filter cake was resuspended in a beaker with 70/30 (w/w) tert-
15 butyl alcohol/deionized water solution (100 g) using a homogenizer. The suspended slurry was transferred back to the initial reaction vessel and the beaker was rinsed with 70/30 solution (56 g) to transfer all of the material. The slurry was stirred for 60 minutes at 400 rpm and 50°C. A 1000 Da diol (2.0 g) was added to the flask and the slurry was stirred for 3 minutes.
20 The mixture was filtered and the filter cake was resuspended in a beaker with the tert-butyl alcohol solution (100 g) using a homogenizer. The suspended slurry was transferred back to the initial reaction vessel and the beaker was rinsed with tert-butanol (44 g) to transfer all of the material. The slurry was stirred for 60 minutes at 400 rpm at 50°C. A 1000 Da diol
25 (1.0 g) was added and the mixture was stirred for three more minutes. The slurry was filtered and the solids were collected to dry in a vacuum oven overnight at 40°C to 50°C.

 The final yield was 8.8 g of dry powder with the following percentages determined by elemental analysis: Zn = 24.2%; Co = 9.9%;
30 and Cl = 4.8%.

Example 4

A DMC catalyst was made at a 2.0 Zn/Co mole ratio with NaCl added to maintain the molar ratio of metal salt anion to metal cyanide anion as follows: a one-liter baffled, round-bottom flask was equipped with a mechanical paddle stirrer, heating mantle and a thermometer. Distilled water (275 g) was added to the flask followed by technical grade zinc chloride (5.73 g) and sodium chloride (60.0 g). Sufficient zinc oxide was added to bring the alkalinity of the system to 3.73% ZnO. Tert-butyl alcohol (40.0 g) was added and the solution was heated to 50°C with stirring at 400 rpm.

A second solution was prepared with potassium hexacyanocobaltate (7.4 g) in distilled water (100 g). This potassium hexacyanocobaltate solution was added to the zinc chloride solution over one hour. After the addition was completed, stirring was continued for an additional 60 minutes at 50°C. A third solution of 1000 Da diol (7.9 g), tert-butyl alcohol (27.1 g), and water (14.9 g) was prepared and added to the flask at the end of the 60 minute period. The flask contents were stirred for an additional three minutes before the solid wet cake was collected by filtration.

The filter cake was resuspended in a beaker with 70/30 (w/w) tert-butyl alcohol/distilled water solution (100 g) using a homogenizer. The suspended slurry was transferred back to the initial reaction vessel and the beaker was rinsed with the 70/30 solution (56 g) to transfer all of the material. The slurry was stirred for 60 minutes at 400 rpm and 50°C. A 1000 Da diol (2.0 g) was added to the flask and the slurry was stirred for three minutes. The mixture was filtered and the filter cake was resuspended in a beaker with the 70/30 solution (100 g) using a homogenizer. The suspended slurry was transferred back to the initial reaction vessel and the beaker was rinsed with tert-butanol (44 g) to transfer all of the material. The slurry was stirred for 60 minutes at

400 rpm and 50° C. Then, a 1000 Da diol (1.0 g) was added and the mixture was stirred for three more minutes. The slurry was filtered and the solids were collected to dry in a vacuum oven overnight at 40°C to 50°C.

The final yield was 8.7 grams of dry powder with the following percentages determined by elemental analysis: Zn = 21.0%; Co = 9.0%; and Cl = 4.8%.

Example 5

A DMC catalyst was made at a 1.5 Zn/Co mole ratio with NaCl added to maintain the molar ratio of metal salt anion to metal cyanide anion as follows: a one-liter baffled, round-bottom flask was equipped with a mechanical paddle stirrer, heating mantle and a thermometer. Distilled water (275 g) was added to the flask followed by technical grade zinc chloride (4.22 g) and sodium chloride (60.0 g). Sufficient zinc oxide was added to bring the alkalinity of the system to 4.88% ZnO. Tert-butyl alcohol (40.0 g) was added and the solution was heated to 50°C with stirring at 400 rpm.

A second solution was prepared with potassium hexacyanocobaltate (7.4 g) in distilled water (100 g). The potassium hexacyanocobaltate solution was added to the zinc chloride solution over one hour. After the addition was completed, stirring was continued for an additional 60 minutes at 50°C. A third solution of 1000 Da diol (7.9 g), tert-butyl alcohol (27.1 g), and water (14.9 g) was prepared and added to the flask at the end of the 60 minute period. The flask contents were stirred for an additional three minutes before the solid wet cake was collected by filtration.

The filter cake was resuspended in a beaker with 70/30 (w/w) tert-butyl alcohol/distilled water solution (100 g) using a homogenizer. The suspended slurry was transferred back to the initial reaction vessel and the beaker was rinsed with the 70/30 solution (56 g) to transfer all of the material. The slurry was stirred for 60 minutes at 400 rpm and 50°C. A 1000 Da diol (2.0 g) was added to the flask and the slurry was stirred for

three minutes. The mixture was filtered and the filter cake was resuspended in a beaker with the 70/30 solution (100 g) using a homogenizer. The suspended slurry was transferred back to the initial reaction vessel and the beaker was rinsed with tert-butanol (44 g) to transfer all of the material. The slurry was stirred for 60 minutes at 400 rpm and 50°C. Then a 1000 Da diol (1.0 g) was added and the mixture was stirred for three more minutes. The slurry was filtered and the solids were collected to dry in a vacuum oven overnight at 40°C to 50°C.

The final yield was 5.7 g of dry powder with the following percentages determined by elemental analysis: Zn = 22.4%; Co = 9.6%; and Cl = 4.2%.

Example 6

A DMC catalyst was made at a 2.2 Zn/Co mole ratio with TBA as follows: a one-liter baffled, round-bottom flask was equipped with a mechanical paddle stirrer, heating mantle and a thermometer. Distilled water (123 g) and tert-butyl alcohol (270 g) were added to the flask followed by technical grade zinc chloride (2.92 g). Sufficient zinc oxide was added to bring the alkalinity of the system to 3.63% ZnO. The mixture was stirred at 400 rpm and heated to 50°C.

A second solution was prepared with potassium hexacyanocobaltate (3.42 g) in distilled water (53 g). This potassium hexacyanocobaltate solution was added to the zinc chloride solution over a 50 minute period. After the addition was completed, stirring was continued for an additional 60 min. at 50°C. A 4000 Da polypropylene glycol (4.0 g) was added to the flask at the end of the 60 minute period. The flask contents were stirred for an additional ten minutes before the solid wet cake was collected by filtration.

The filter cake was resuspended in the reaction vessel with 90/10 (w/w) tert-butyl alcohol/distilled water solution (300 g) using a paddle stirrer. The slurry was stirred for 60 minutes at 400 rpm and 50°C. The mixture was filtered and the filter cake was resuspended in the reaction

vessel with the tert-butyl alcohol solution (300g) using a paddle stirrer. The slurry was stirred for 60 minutes at 400 rpm and 50°C. The slurry was filtered and the solids were collected to dry in a vacuum oven overnight at 40°C to 50°C.

- 5 The final yield was 5.4 g of dry powder with the following percentages determined by elemental analysis: Zn = 20.5%; Co = 9.4%; and Cl = 4.1%.

Example 7

- 10 A DMC catalyst was made at a 2.07 Zn/Co mole ratio with TBA as follows: a one-liter baffled, round-bottom flask was equipped with a mechanical paddle stirrer, heating mantle and a thermometer. Distilled water (123 g) and tert-butyl alcohol (270 g) were added to the flask followed by technical grade zinc chloride (6.3 g). The mixture was stirred
15 at 500 rpm and heated to 50°C.

- A second solution was prepared with potassium hexacyano-cobaltate (8.46 g) and sufficient potassium hydroxide in distilled water (53 g) to bring the alkalinity of the system to 4.3%. This potassium hexacyanocobaltate solution was added to the zinc chloride solution over
20 a 2.8 hour period. After the addition was completed, stirring was continued for an additional 60 minutes at 50°C. A third solution of 1000 Da diol (6.4 g), tert-butyl alcohol (10 g), and water (6 g) was prepared and added to the flask at the end of the 60 minute period. The flask contents were stirred for an additional ten minutes before the solid
25 wet cake was collected by filtration.

- The filter cake was resuspended in the reaction vessel with 90/10 (w/w) tert-butyl alcohol/distilled water solution (200 g) using a paddle stirrer. The slurry was stirred for 60 minutes at 500 rpm and 50°C. The mixture was filtered and the filter cake was resuspended in the reaction
30 vessel with the tert-butyl alcohol solution (200 g) using a paddle stirrer.

The slurry was stirred for 60 minutes at 500 rpm and 50°C. The slurry was filtered and the solids were collected to dry in a vacuum oven for four hours at 40°C to 50°C.

The final yield was 11.5 g of dry powder with the following percentages determined by elemental analysis: Zn = 21.0%; Co = 9.4%; and Cl = 5.4%.

Example 8

A DMC catalyst was made at a 2.4 Zn/Co mole ratio with 700 Da monol in TBA as follows: a one-liter baffled, round-bottom flask was equipped with a mechanical paddle stirrer, heating mantle and a thermometer. Distilled water (123 g), tert-butyl alcohol (254 g), and monol (13.8 g) were added to the flask followed by technical grade zinc chloride (2.65 g). The monol was prepared by reacting about 8 moles of propylene oxide with one mole of a C₁₂-C₁₅ fatty alcohol. The mixture was stirred at 500 rpm and heated to 50°C.

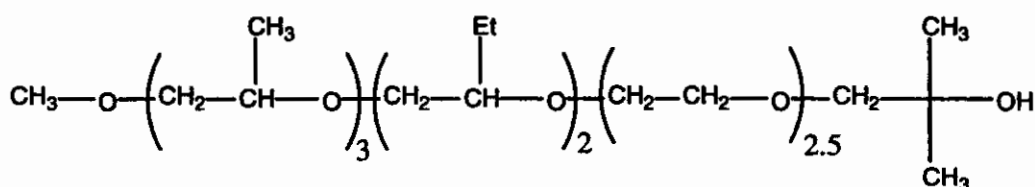
A second solution was prepared with potassium hexacyanocobaltate (3.42 g) and sufficient potassium hydroxide in distilled water (53 g) to bring the alkalinity of the system to 5.46%. This potassium hexacyanocobaltate solution was added to the zinc chloride solution over a 2.4 hour period. After the addition was completed, stirring was continued for an additional 60 minutes at 50°C. A 4000 Da polypropylene glycol (4 g) was added to the flask at the end of the 60 minute period. The flask contents were stirred for an additional ten minutes before the solid wet cake was collected by filtration.

The filter cake was resuspended in the reaction vessel with 90/10 (w/w) tert-butyl alcohol/distilled water solution (300 g). The slurry was stirred for 60 minutes at 500 rpm and 50°C. The mixture was filtered and the filter cake was resuspended in the reaction vessel with the tert-butyl alcohol solution (300 g). The slurry was stirred for 60 minutes at 500 rpm and 50°C. The slurry was filtered and the solids were collected to dry in a vacuum oven for four hours at 40°C to 50°C.

The final yield was 5.6 g of dry powder with the following percentages determined by elemental analysis: Zn = 23.6%; Co = 10.6%; and Cl = 4.0%.

5 Example 9

A DMC catalyst was made at a 2.0 Zn/Co mole ratio with a 560 Da mixed oxide monol in water as follows: a one-liter baffled, round-bottom flask was equipped with a mechanical paddle stirrer, heating mantle and a thermometer. Distilled water (375 g) and a 560 Da monol (30.6 g) were added to the flask followed by technical grade zinc chloride (2.61 g). The monol was prepared from tripropylene glycol monomethyl ether, butylene oxide, ethylene oxide, and isobutylene oxide and had the following structure:



15 Sufficient zinc oxide was added to bring the alkalinity of the system to 4.04% ZnO. The mixture was stirred at 400 rpm and heated to 65°C.

A second solution was prepared with potassium hexacyano-cobaltate (3.42 g) in distilled water (53 g). This potassium hexacyano-cobaltate solution was added to the zinc chloride solution over a one hour period. After the addition was completed, stirring was continued for an additional 60 minutes at 65°C. The flask contents were collected by filtration. The filter cake was resuspended in 90/10 (w/w) tetrahydrofuran/distilled water solution (150 g) using a paddle stirrer and mixed for 35 minutes at 50°C. The slurry was filtered and the solids were collected to dry in a vacuum oven overnight at ambient temperature.

The final yield was 7.2 g of solid with the following percentages determined by elemental analysis: Zn = 13.9%; Co = 6.3%; and Cl = 3.3%.

One factor controlling catalyst activity is the amount of alkalinity actually incorporated into the compound. The alkalinity of aqueous zinc chloride solutions reported in Table I below was measured by potentiometric titration with standardized 0.1N aqueous hydrochloric acid as follows: aqueous HCl (about 0.1N) was standardized by potentiometrically titrating accurately weighed samples (about 0.15 g) of dry tris(hydroxymethyl) aminomethane (THAM) in distilled water (80 ml). The endpoint was determined graphically.

$$\text{Normality of the HCl solution} = \frac{\text{\# grams of THAM}}{0.12114 \times \text{volume of HCl (in ml)}}$$

Zinc chloride samples were analyzed as follows. A sample was dissolved in distilled water to give an approximately 8.5 wt. % zinc chloride solution. The sample was titrated with standardized 0.1N aqueous HCl solution. The volume of titrant needed to reach the equivalence point was determined graphically. Alkalinity (expressed as wt. % ZnO) was calculated as follows:

$$\text{Wt.\% ZnO} = \frac{(V \times N \times 4.0685 \times 100)}{(W \times \% \text{ZnCl}_2)}$$

where V represents the volume of HCl (in ml) needed to reach the equivalence point, N represents the normality of the HCl solution, W represents the weight of the zinc chloride sample (in grams), and % ZnCl₂ represents the weight percentage of zinc chloride in the original sample.

Table I summarizes the alkalinity, zinc to cobalt mole ratio, ligand to zinc mole ratio, water to cation mole ratio and the catalyst morphology as determined by X-ray diffraction pattern for the catalysts made in the examples. As will be apparent by reference to Table I, the inventive DMC catalysts, although having a Zn/Co ratio much below those of previously disclosed catalysts, had a substantially amorphous X-ray diffraction pattern. The catalyst produced in Comparative Example 1 (according to U.S. Pat. No. 5,783,513) exemplifies this substantially amorphous pattern.

TABLE I

Ex. No.	Alkalinity (wt.% ZnO)	Zn/Co Mole ratio	Ligand/Zn Mole ratio	H ₂ O/Cation Mole ratio	Cl/Co Mole Ratio	X-ray pattern
C-1	0.48	25.1	0.97	33	50	Substantially amorphous
C-2	0.32	2.0	10.9	187	4	Substantially crystalline
3*	6.49	2.2	10.9	18	50	Substantially amorphous
4*	3.73	2.0	12.1	18	50	Substantially amorphous
5*	4.88	1.5	16.1	18	49	Substantially amorphous
6	3.63	2.2	160	181	4	Substantially amorphous
7	4.3	2.07	79	90	4	Substantially amorphous
8	5.46	2.37	140 (TBA) 0.81 (polyol)	177	5	Substantially amorphous
9	4.04	2.0	2.7	475	4	Substantially amorphous

* - NaCl used in catalyst preparation.

- 5 Figure 1 graphically demonstrates the difference between a crystalline catalyst such as that produced in Comparative Example 2 and the substantially amorphous catalysts made by Comparative Example 1 and in one embodiment of the inventive processes as represented by Example 5. As can be appreciated by reference to Fig. 1, the crystalline
- 10 catalyst of Comparative Example 2 has numerous sharp lines in the X-ray diffraction pattern, whereas the substantially amorphous catalysts made in Comparative Example 1 and in Example 5 do not. Figures 2 and 3 provide the X-ray diffraction patterns for the substantially amorphous DMC catalysts produced by the inventive processes described in Examples 7
- 15 and 8, respectively.

Catalyst Activity

Several of the catalysts made herein were evaluated for propoxylation activity by preparing a 6000 Da triol from a glycerin-based PO, block polyol having an OH number of 238 and a functionality of about

- 5 3. Briefly, a polyol reactor was equipped with two six-inch pitched blade turbines, a Rushton turbine at the bottom of the impeller shaft and baffles. A dip tube delivered the oxide feed to the reactor just below the Rushton turbine. The unit provided approximately 40-50 horsepower/1000 gallons of mixing power when the filled reactor operated at 600 rpm. Rates were
- 10 calculated by monitoring drops in PO partial pressures the moment oxide addition was completed. To reduce or eliminate mass transfer initiations between the liquid and vapor phases, the batch size was set such that the last blade was half covered to encourage maximum interfacial mixing.

- Calculated apparent rate constants (k_{app}) are shown in Table II
- 15 below. These values were determined by plotting the natural logarithm of PO partial pressure versus time and determining the slope of the resultant straight line.

TABLE II

Ex. No.	Viscosity (cSt @ 25°C)	OH Number (mgKOH/g)	Unsaturation (meq/g)	Catalyst (ppm)	Activity (k_{app})
C-1	1512	27.9	0.005	24	2.17
4*	1800	28.1	0.006	24	1.24
5*	1610	28.0	0.007	24	2.19
7	1421	27.9	0.006	25	1.00
8	1319	27.4	0.0051	50	2.06
9	1180	29.7	0.0287	218	0.45

- 20 * - NaCl used in catalyst preparation

- The foregoing examples of the present invention are offered for the purpose of illustration and not limitation. It will be apparent to those skilled in the art that the embodiments described herein may be modified or
- 25 revised in various ways without departing from the spirit and scope of the invention. The scope of the invention is to be measured by the appended claims.

WHAT IS CLAIMED IS:

1. A process for preparing a double metal cyanide (DMC) catalyst, comprising reacting in aqueous solution at a molar ratio of water to total cations of less than about 150:
 - 5 a transition metal salt having an alkalinity of at least about 2 wt. % as transition metal oxide, based on the amount of transition metal salt; with
 - a metal cyanide salt, at a molar ratio of transition metal to cyanide salt metal of less than about 2.9:1,
 - 10 in the presence of an organic complexing ligand at a molar ratio of organic complexing ligand to transition metal of greater than about 1, and in the presence of a cyanide-free compound comprising an anion and an alkali metal at a molar ratio of cyanide-free anion to metal cyanide salt anion of greater than about 3,
 - 15 wherein the double metal cyanide (DMC) catalyst is substantially amorphous.
2. The process according to Claim 1, wherein the transition metal salt is chosen from zinc chloride, zinc bromide, zinc acetate, zinc
20 acetylacetonate, zinc benzoate, zinc nitrate, iron(II) sulfate, iron(II) bromide, cobalt(II) chloride, cobalt(II) thiocyanate, nickel(II) formate, nickel(II) nitrate and mixtures thereof.
3. The process according to Claim 1, wherein the transition metal salt
25 is zinc chloride.
4. The process according to Claim 1, wherein the metal cyanide salt is chosen from potassium hexacyanocobaltate(III), potassium hexacyanoferrate(II), potassium hexacyanoferrate(III), calcium
30 hexacyanocobaltate(III) and lithium hexacyanocobaltate(III).

5. The process according to Claim 1, wherein the metal cyanide salt is potassium hexacyanocobaltate(III).
6. The process according to Claim 1, wherein the organic complexing
5 ligand is chosen from alcohols, aldehydes, ketones, ethers, esters, amides, ureas, nitrites, sulfides and mixtures thereof.
7. The process according to Claim 1, wherein the organic complexing
ligand is chosen from 2-methyl-3-butene-2-ol, 2-methyl-3-butenyl-2-ol and
10 tert-butyl alcohol (TBA).
8. The process according to Claim 1, wherein the cyanide-free compound is sodium chloride.
- 15 9. The process according to Claim 1, further including adding a functionalized polymer following the step of reacting.
10. The process according to Claim 9, wherein the functionalized polymer is a polyether polyol.
20
11. The process according to Claim 1, further including the steps of:
isolating the substantially amorphous double metal cyanide (DMC)
catalyst;
washing the isolated, substantially amorphous double metal
25 cyanide (DMC) catalyst; and
drying the isolated, substantially amorphous double metal cyanide
(DMC) catalyst.
12. The process according to Claim 1, wherein the molar ratio of
30 transition metal cation to cyanide salt metal anion is less than about 1.5:1.

13. The process according to Claim 1, wherein the molar ratio of water to total cations is less than about 75.
14. The process according to Claim 1, wherein the molar ratio of water to total cations is between about 10 and about 75.
15. The process according to Claim 1, wherein the molar ratio of the organic complexing ligand to transition metal is greater than about 5.
16. The process according to Claim 1, wherein the molar ratio of the organic complexing ligand to transition metal is between about 1 and about 50.
17. The process according to Claim 1, wherein molar ratio of the cyanide-free anion to the metal cyanide anion is greater than about 6.
18. The process according to Claim 1, wherein the transition metal salt has an alkalinity of between about 2.8 and about 15 wt. % as transition metal oxide based on the amount of transition metal salt.
19. The process according to Claim 1, wherein the transition metal salt has an alkalinity of between about 3 and about 12 wt. % as transition metal oxide based on the amount of transition metal salt.
20. The substantially amorphous double metal cyanide (DMC) catalyst prepared by the process according to Claim 1.
21. In a process for producing a polyether polyol by polyaddition of an alkylene oxide onto a starter compound containing active hydrogen atoms, the improvement comprising conducting the polyaddition in the presence of the substantially amorphous double metal cyanide (DMC) catalyst prepared by the process according to Claim 1.

22. A process for preparing a double metal cyanide (DMC) catalyst, comprising:
reacting in aqueous solution at a molar ratio of water to total cations of
5 less than about 150:
a transition metal salt having an alkalinity of at least about 2 wt. %
as transition metal oxide, based on the amount of transition
metal salt; with
a metal cyanide salt, at a molar ratio of transition metal to cyanide
10 salt metal of less than about 2.9:1,
in the presence of a cyanide-free compound comprising an anion and an
alkali metal at a molar ratio of cyanide-free anion to metal cyanide salt
anion of greater than about 3 to produce the substantially amorphous
double metal cyanide (DMC) catalyst, and
15 adding an organic complexing ligand at a molar ratio of organic
complexing ligand to transition metal of greater than about 1.
23. A process for preparing a substantially amorphous double metal
cyanide (DMC) catalyst, comprising reacting in aqueous solution at a
20 molar ratio of water to total cations of less than about 250:
a transition metal salt having an alkalinity of at least about 2 wt. %
as transition metal oxide based on the amount of transition
metal salt; with
a metal cyanide salt at a molar ratio of transition metal cation to
25 cyanide salt metal anion of less than about 2.9:1 and at a
ratio of cyanide-free anion to metal cyanide anion of between
about 3 and about 6,
in the presence of an organic complexing ligand at a molar ratio of organic
complexing ligand to transition metal of greater than about 5.
30 wherein the double metal cyanide (DMC) catalyst is substantially
amorphous.

24. The process according to Claim 23, wherein the transition metal salt is chosen from zinc chloride, zinc bromide, zinc acetate, zinc acetylacetonate, zinc benzoate, zinc nitrate, iron(II) sulfate, iron(II) bromide, cobalt(II) chloride, cobalt(II) thiocyanate, nickel(II) formate, nickel(II) nitrate and mixtures thereof.
25. The process according to Claim 23, wherein the transition metal salt is zinc chloride,
26. The process according to Claim 23, wherein the metal cyanide salt is chosen from potassium hexacyanocobaltate(III), potassium hexacyanoferrate(II), potassium hexacyanoferrate(III), calcium hexacyanocobaltate(III) and lithium hexacyanocobaltate(III).
27. The process according to Claim 23, wherein the metal cyanide salt is potassium hexacyanocobaltate(III).
28. The process according to Claim 23, wherein the organic complexing ligand is chosen from alcohols, aldehydes, ketones, ethers, esters, amides, ureas, nitrites, sulfides and mixtures thereof.
29. The process according to Claim 23, wherein the organic complexing ligand is 2-methyl-3-butene-2-ol, 2-methyl-3-butenyl-2-ol and tert-butyl alcohol (TBA).
30. The process according to Claim 23, further including adding a functionalized polymer after the step of reacting.
31. The process according to Claim 30, wherein the functionalized polymer is a polyether polyol.

32. The process according to Claim 23, further including the steps of:
isolating the substantially amorphous double metal cyanide (DMC)
catalyst;
washing the isolated, substantially amorphous double metal
5 cyanide (DMC) catalyst; and
drying the isolated, substantially amorphous double metal cyanide
(DMC) catalyst.
33. The process according to Claim 23, wherein the molar ratio of
10 transition metal cation to cyanide salt metal anion is less than about 2.5:1.
34. The process according to Claim 23, wherein the molar ratio of water
to total cations less than about 200.
- 15 35. The process according to Claim 23, wherein the molar ratio of water
to total cations is between about 75 and about 200.
36. The process according to Claim 23, wherein the molar ratio of the
organic complexing ligand to transition metal is greater than about 10.
20
37. The process according to Claim 23, wherein the molar ratio of the
organic complexing ligand to transition metal is between about 10 and
about 200.
- 25 38. The process according to Claim 23, wherein the transition metal salt
has an alkalinity of between about 2.8 and about 15 wt. % as transition
metal oxide based on the amount of transition metal salt.
39. The process according to Claim 23, wherein the transition metal salt
30 has an alkalinity of between about 3 and about 12 wt. % as transition
metal oxide based on the amount of transition metal salt.

40. The substantially amorphous double metal cyanide (DMC) catalyst prepared by the process according to Claim 23.

5 41. In a process for producing a polyether polyol by polyaddition of an alkylene oxide onto a starter compound containing active hydrogen atoms, the improvement comprising conducting the polyaddition in the presence of the substantially amorphous double metal cyanide (DMC) catalyst prepared by the process according to Claim 23.

10 42. A process for preparing a substantially amorphous double metal cyanide (DMC) catalyst, comprising reacting in aqueous solution at a molar ratio of water to total cations is greater than about 100:
a transition metal salt having an alkalinity of at least about 2 wt. %
as transition metal oxide based on the amount of transition
15 metal salt, with
a metal cyanide salt at a molar ratio of transition metal cation to cyanide salt metal anion of less than about 2.9:1 and at a ratio of cyanide-free anion to metal cyanide anion of between about 3 and about 6,
20 in the presence of
a functionalized polymer at a molar ratio of functionalized polymer to transition metal is less than about 10 and,
optionally an organic complexing ligand,
wherein the double metal cyanide (DMC) catalyst is substantially
25 amorphous.

43. The process according to Claim 42, wherein the transition metal salt is chosen from zinc chloride, zinc bromide, zinc acetate, zinc
acetonylacetate, zinc benzoate, zinc nitrate, iron(II) sulfate, iron(II)
30 bromide, cobalt(II) chloride, cobalt(II) thiocyanate, nickel(II) formate, nickel(II) nitrate and mixtures thereof.

44. The process according to Claim 42, wherein the transition metal salt is zinc chloride,
45. The process according to Claim 42, wherein the metal cyanide salt is chosen from potassium hexacyanocobaltate(III), potassium hexacyanoferrate(II), potassium hexacyanoferrate(III), calcium hexacyanocobaltate(III) and lithium hexacyanoiridate(III).
46. The process according to Claim 42, wherein the metal cyanide salt is potassium hexacyanocobaltate(III).
47. The process according to Claim 42, wherein the organic complexing ligand is chosen from alcohols, aldehydes, ketones, ethers, esters, amides, ureas, nitrites, sulfides and mixtures thereof.
48. The process according to Claim 42, wherein the organic complexing ligand is 2-methyl-3-butene-2-ol, 2-methyl-3-butenyl-2-ol and tert-butyl alcohol (TBA).
49. The process according to Claim 42, wherein the functionalized polymer is a polyether polyol.
50. The process according to Claim 42, further including the steps of:
isolating the substantially amorphous double metal cyanide (DMC) catalyst;
washing the isolated, substantially amorphous double metal cyanide (DMC) catalyst; and
drying the isolated, substantially amorphous double metal cyanide (DMC) catalyst.
51. The process according to Claim 42, wherein the molar ratio of transition metal cation to cyanide salt metal anion is less than about 2.5:1.

52. The process according to Claim 42, wherein the molar ratio of water to total cations is greater than about 150.

53. The process according to Claim 42, wherein the molar ratio of water
5 to total cations is between about 150 and about 500.

54. The process according to Claim 42, wherein the molar ratio of the functionalized polymer to transition metal is greater than about 5.

10 55. The process according to Claim 42, wherein the molar ratio of the functionalized polymer to transition metal is between about 0.25 and about 5.

56. The process according to Claim 42, wherein the transition metal salt
15 has an alkalinity of between about 2.8 and about 15 wt. % as transition metal oxide based on the amount of transition metal salt.

57. The process according to Claim 42, wherein the transition metal salt has an alkalinity of between about 3 and about 12 wt. % as transition
20 metal oxide based on the amount of transition metal salt.

58. The substantially amorphous double metal cyanide (DMC) catalyst prepared by the process according to Claim 42.

25 59. In a process for producing a polyether polyol by polyaddition of an alkylene oxide onto a starter compound containing active hydrogen atoms, the improvement comprising conducting the polyaddition in the presence of the substantially amorphous double metal cyanide (DMC) catalyst prepared by the process according to Claim 42.