Claims

1. A method for quenching a polymerisation process comprising the reaction of carbon dioxide with an epoxide in the presence of a bimetallic metal complex catalyst, the method comprising the step of deactivation of the catalyst by contacting the catalyst with an acid effective to deactivate the catalyst.

2. A method for purifying a polymer product formed from a polymerisation process comprising the reaction of carbon dioxide with an epoxide in the presence of a bimetallic metal complex catalyst, the method comprising the steps of:

   (i) quenching the polymerisation process by contacting the catalyst with an acid effective to deactivate the catalyst;

   (ii) removing the deactivated catalyst from the polymer product by contacting said deactivated catalyst and polymer product with a solid phase and/or by precipitation; and

   (iii) optionally reactivating the catalyst by contacting the deactivated catalyst with an anion.

3. A method according to claim 1 or claim 2, wherein the molar ratio of acid to catalyst in the deactivation step is less than or equal to 20:1 of the acid to catalyst mole ratio for the deactivation reaction.

4. A method according to claim 3, wherein the molar ratio of acid to catalyst in the deactivation step is less than or equal to 10:1 of the acid to catalyst mole ratio for the deactivation reaction.

5. A method according to any one of claims 1 to 4, wherein the acid contains an anion effective to initiate the polymerisation process.

6. A method for quenching a polymerisation process comprising the reaction of carbon dioxide with an epoxide in the presence of a metal complex catalyst, the method comprising the step of deactivation of the catalyst by contacting the catalyst with an acid effective to deactivate the catalyst and which contains an anion effective to initiate the polymerisation process and wherein the molar ratio of acid to catalyst in the deactivation step is less than or equal to 20:1 of the acid to catalyst mole ratio for the deactivation reaction.

7. A method for purifying a polymer product formed from a polymerisation process comprising the reaction of carbon dioxide with an epoxide in the presence of a metal complex catalyst, the method comprising the steps of:

   (i) quenching the polymerisation process by contacting the catalyst with an acid containing an anion effective to initiate the polymerisation process and effective to deactivate the catalyst, wherein the molar ratio of acid to catalyst in the deactivation step is less than or equal to 20:1 of the acid to catalyst mole ratio for the reaction;

(ii) removing the deactivated catalyst from the polymer product by contacting said deactivated catalyst and polymer product with a solid phase and/or by precipitation; and

(iii) optionally reactivating the catalyst by contacting the deactivated catalyst with an anion.

8. A method according to claim 7, wherein the molar ratio of acid to catalyst in the deactivation step is less than or equal to 10:1 of the acid to catalyst mole ratio for the reaction.

9. A method for purifying a polymer product formed from a polymerisation process comprising the reaction of carbon dioxide with an epoxide in the presence of a bimetallic metal complex catalyst, the method comprising the steps of:

(i) quenching the polymerisation process by contacting the catalyst with an acid effective to deactivate the catalyst;

(ii) removing the deactivated catalyst from the polymer product by contacting said deactivated catalyst and polymer product with a solid phase and/or by precipitation; and

(iii) optionally reactivating the catalyst by contacting the deactivated catalyst with an anion;

wherein steps (i) and (ii) are performed simultaneously.

10. A method for purifying a polymer product formed from a polymerisation process comprising the reaction of carbon dioxide with an epoxide in the presence of a bimetallic metal complex catalyst, the method comprising the steps of:

(i) quenching the polymerisation process by contacting the catalyst with an acid effective to deactivate the catalyst;

(ii) removing the deactivated catalyst from the polymer product by contacting said deactivated catalyst and polymer product with a solid phase and/or by precipitation; and

(iii) optionally reactivating the catalyst by contacting the deactivated catalyst with an anion;

wherein the acid effective to deactivate the catalyst is present on a solid support, so that the deactivation step (i) and removal step (ii) is performed simultaneously.

11. A method according to claim 2 to 8, wherein the step of contacting the catalyst with an acid effective to deactivate the catalyst is performed simultaneously with the step of contacting the deactivated catalyst and polymer product with a solid phase to remove the deactivated catalyst.

12. A method according to any one of claims 1 to 11, wherein the acid is a carboxylic acid.

13. A method according to claim 12, wherein the acid is a functionalised carboxylic acid comprising one or more other functional groups in addition to the acid group effective to form a stable bond or interaction with one or more of the metal centres of the catalyst.

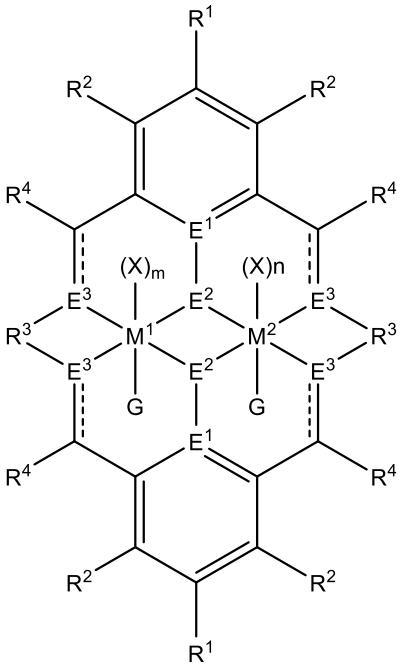
14. A method according to claim 13, wherein the functional groups are selected from -OH, -SO_3H, -$P(O)(OH)_2$, -$N(R^9)_2$ or –COOH, wherein R^9 is independently selected from hydrogen, an aliphatic, heteroaliphatic, alicyclic, heteroalicyclic, aryl or heteroaryl group.

15. A method according to claim 14, wherein the functionalised carboxylic acid is a dicarboxylic, tricarboxylic or hydroxy carboxylic acid.

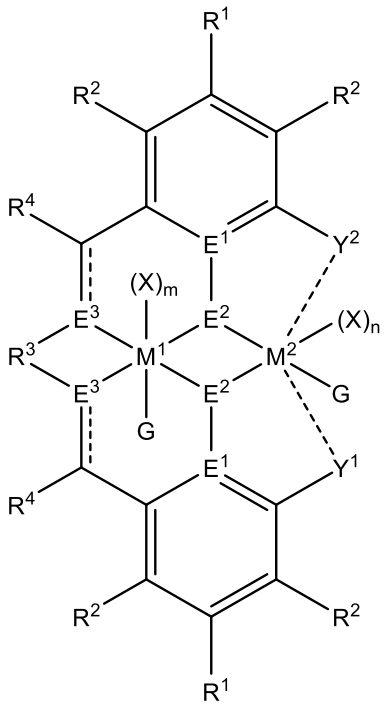
16. A method according to any one of claims 1 or 15, wherein the acid contains an anion selected from $OC(O)CH_3$, $OC(O)CH_2CH_3$, $OC(O)(CH_2)_2CH_3$, $OC(O)(CH_2)_3CH_3$, $OC(O)(CH_2)_4CH_3$, $OC(O)(CH_2)_5CH_3$, $OC(O)(CH_2)_6CH_3$, $OC(O)C(CH_3)_3$, $OC(O)C_6H_5$, $OC(O)CCCl_3$ and/or $OC(O)CF_3$, most preferably $OC(O)CH_3$.

17. A method according to any one of claims 1 to 16, wherein the acid has a pKa of at least 2.5.

18. A method according to any one of claims 1 to 17, the metal complex catalyst is of formula (I) or formula (II):



formula (I),



formula (II)

wherein R^1 and R^2 are independently selected from hydrogen, halide, a nitro group, a nitrile group, an imine group, -$NCR^{13}R^{14}$, an amine, an ether –OR^{15}, –$R^{16}OR^{17}$, an ester group –$OC(O)R^{10}$ or –$C(O)OR^{10}$, an amido group –$NR^9C(O)R^9$ or –$C(O)$-$NR^9(R^9)$, -COOH, -$C(O)R^{15}$, –$OP(O)(OR^{18})(OR^{19})$,–$P(O)R^{20}R^{21}$, -$P(O)(OR)(OR)$, -$OP(O)R(OR)$, a silyl group, a silyl ether group, a sulfoxide group, a sulfonyl group, a sulfinate group or an acetylide group or an optionally substituted alkyl, alkenyl, alkynyl, haloalkyl, aryl, heteroaryl, alkoxy, aryloxy, alkylthio, arylthio, alicyclic or heteroalicyclic group;

R^3 is independently selected from optionally substituted alkylene, alkenylene, alkynylene, heteroalkylene, heteroalkenylene, heteroalkynylene, arylene, heteroarylene or cycloalkylene, wherein alkylene, alkenylene, alkynylene, heteroalkylene, heteroalkenylene and heteroalkynylene, may optionally be interrupted by aryl, heteroaryl, alicyclic or heteroalicyclic;

R^4 is independently selected from H, or optionally substituted aliphatic, heteroaliphatic, alicyclic, heteroalicyclic, aryl, heteroaryl, alkylheteroaryl or alkylaryl;

R^9, R^{10}, R^{13}, R^{14}, R^{18}, R^{19}, R^{20} and R^{21} are independently selected from hydrogen or an aliphatic, heteroaliphatic, alicyclic, heteroalicyclic, aryl or heteroaryl group;

E^1 is C, E^2 is O, S or NH or E^1 is N and E^2 is O;

E^3 is N, NR^5, O or S, wherein when E^3 is N, ------ is ═══, and when E^3 is NR^5, O or S, ------ is ———;

R^5 is independently selected from H, or optionally substituted aliphatic, heteroaliphatic, alicyclic, heteroalicyclic, aryl, heteroaryl, alkylheteroaryl, -alkyl$C(O)OR^{10}$, -alkylnitrile, or alkylaryl;

X, when present, is independently selected from $OC(O)R^x$, OSO_2R^x, $OSOR^x$, $OSO(R^x)_2$, $S(O)R^x$, OR^x, phosphinate, halide, nitrate, hydroxyl, carbonate, amino, nitro, amido or optionally substituted aliphatic, heteroaliphatic, alicyclic, heteroalicyclic, aryl or heteroaryl;

m and n are independently integers selected from the range 0-3, such that the sum of m and n is 0-5;

R^x is independently selected from hydrogen or an aliphatic, heteroaliphatic, alicyclic, heteroalicyclic, aryl or heteroaryl group;

each G is independently absent or a neutral or anionic donor ligand which is a Lewis base;

Y^1 and Y^2, when present, are independently a neutral or anionic donor group capable of donating a lone pair to the metal M^2; and

M^1 and M^2 are independently selected from Zn(II), Cr(II), Co(II), Cu(II), Mn(II), Mg(II), Ni(II), Fe(II), Ti(II), V(II), Cr(III), Co(III), Mn(III), Ni(III), Fe(III), Ca(II), Ge(II), Al(III), Ti(III), V(III), Ge(IV), Y(III), Sc(III) or Ti(IV).

19. A method according to any one of claims 2 to 5 or 7 to 18, wherein the solid phase is an inorganic solid phase or an ion exchange resin.

20. A method according to claim 19, wherein the ion exchange resin is an acidic ion exchange resin.

21. A method according to any one of claims 2 to 18, wherein the deactivated catalyst is caused to precipitate from the crude polymer product by the addition of one or more precipitant or precipitates automatically.

22. A method according to any one of claims 2 to 21, wherein the anion is derived from an acid.

23. A method according to claim 22, wherein the anion is derived from one or more carboxylic acid(s).

24. A method according to claim 19, wherein the anion is derived from a functionalised carboxylic acid comprising one or more other functional groups in addition to the acid effective to form a stable bond or interaction with one or more of the metal centres of the catalyst, a metal salt of a functional carboxylic acid comprising one or more other functional groups effective to form a stable bond or interaction with one or more of the metal centres of the catalyst or combinations thereof.

25. A method according to claim 24, wherein the functional groups are selected from -OH, $-SO_3H$, $-P(O)(OH)_2$, $-N(R^9)_2$ or –COOH, wherein R^9 is independently selected from hydrogen, an aliphatic, heteroaliphatic, alicyclic, heteroalicyclic, aryl or heteroaryl group.

26. A method according to claim 25, wherein the functionalised carboxylic acid is a dicarboxylic, tricarboxylic or hydroxy carboxylic acid.

27. A method according to any one of claims 22 to 26, wherein the anion is derived from an acid which has a pKa of at least 2.5.

28. A method according to any one of claims 1 to 5 or 7 to 27, wherein the anion is able to act as an initiator for the polymerisation process.

29. A method according to claim 28, wherein the anion is selected from $OC(O)CH_3$, $OC(O)CH_2CH_3$, $OC(O)(CH_2)_2CH_3$, $OC(O)(CH_2)_3CH_3$, $OC(O)(CH_2)_4CH_3$, $OC(O)(CH_2)_5CH_3$, $OC(O)(CH_2)_6CH_3$, $OC(O)C(CH_3)_3$, $OC(O)C_6H_5$, $OC(O)CCCl_3$ and/or $OC(O)CF_3$, most preferably $OC(O)CH_3$.

30. A method according to any one of claims 1 to 29, wherein the acid does not include trimesic acid.