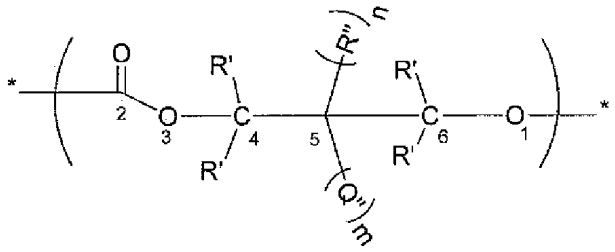
each Q" is an independent group comprising a guanidinium and/or an isothiouronium group.

[0007a] In an aspect, there is provided an antimicrobial cationic polymer, comprising a cationic subunit of formula (A-1):



(A-1),

wherein

atoms 1-6 are backbone atoms of the cationic polymer,

m is 1 or 2,

n is 0 or 1, wherein when m is 2, n is 0,

each R' is an independent monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

R" is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

each Q" is an independent group comprising a guanidinium and/or isothiouronium group, and the degree of polymerization is in the range of from 5 to 20,

wherein the cationic polymer has a structure in accordance with formula (B-1):

Z'-P'-Z" (B-1),

wherein

Z' is a monovalent first end group comprising 1 to 40 carbons,

Z" is a monovalent second end group selected from the group consisting of hydrogen and groups comprising 1 to 40 carbons, and

P' is a polymer chain comprising the cationic subunit of formula (A-1);

or the cationic polymer has a structure in accordance with formula (B-2):

Z^b-P^b-C'-P^b-Z^b (B-2),

wherein

each P^b is an independent polymer chain comprising the cationic subunit of formula (A-1),

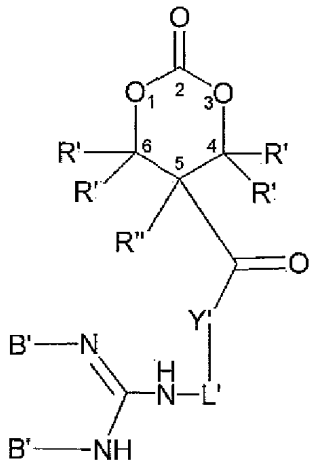
C' is a divalent linking group (core group) comprising 2 to 25 carbons, wherein C' comprises two heteroatoms independently selected from the group consisting of nitrogen, oxygen, and sulfur, wherein the heteroatoms are covalently linked to respective polymer chains P^b, and

each Z^b is an independent monovalent end group selected from the group consisting of hydrogen and groups comprising 1 to 40 carbons.

[0008] In another aspect, there is provided a method of killing a microbe, comprising contacting the microbe with an above-described cationic polymer.

[0009] Further disclosed is a method of forming an above-described cationic polymer, comprising:

forming an initial polymer by organocatalyzed ring opening polymerization of a cyclic carbonate monomer of formula (M-1):



(M-1),

wherein

ring atoms are numbered 1 to 6,

each B' is an independent acid-labile protecting group,

L' is a divalent hydrocarbon radical comprising 2 to 30 carbons,

each R' is an independent monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

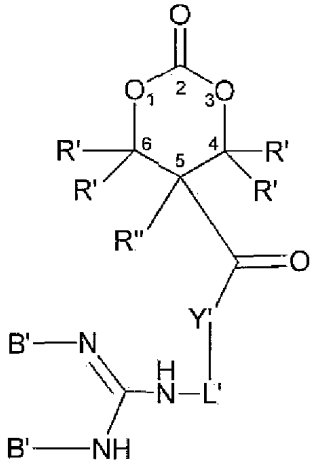
R" is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons, and

Y' is *-O-* or *-N(H)-*; and

treating the initial polymer with a protic acid, thereby forming the cationic polymer.

[0009a] In another aspect, there is provided a method of forming the above-described cationic polymer, comprising:

forming an initial polymer by organocatalyzed ring opening polymerization of a cyclic carbonate monomer of formula (M-1):



(M-1),

wherein

ring atoms are numbered 1 to 6,

each B' is an independent acid-labile protecting group,

L' is a divalent hydrocarbon radical comprising 2 to 30 carbons,

each R' is an independent monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

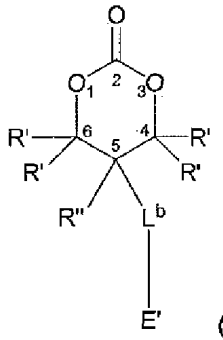
R" is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons, and

Y' is *-O-* or *-N(H)-*; and

treating the initial polymer with a protic acid, thereby forming the cationic polymer or wherein each R' is hydrogen and R" is methyl or ethyl.

[0009b] In another aspect, there is provided a method of forming the above-described cationic polymer, comprising:

forming an initial polymer by organocatalyzed ring opening polymerization of a cyclic carbonate monomer of formula (M-6):



(M-6),

wherein

the ring atoms are shown numbered 1 to 6,

L^b is a divalent linking group comprising 1 or more carbons,

E' is a substituent capable of undergoing a nucleophilic substitution reaction with thiourea to form an isothiouronium group,

each R' is an independent monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons, and

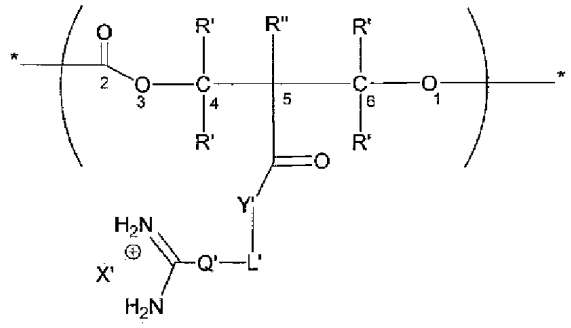
R" is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons; and

treating the initial polymer with thiourea, thereby forming the cationic polymer.

[0010] Additionally in another aspect, there is provided an antimicrobial particle, comprising:

a core comprising silica; and

a plurality of independent surface groups covalently linked to the core, wherein one or more of the surface groups comprises one or more cationic subunits of formula (A-2):



(A-2),

wherein

atoms 1-6 are backbone atoms of the surface groups,

L' is a divalent hydrocarbon radical comprising 2 to 30 carbons,

Q' is *-N(H)-* or *-S-*,

each R' is an independent monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

R" is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

X' is a negative-charged counterion, and

Y' is *-O-* or *-N(H)-*.

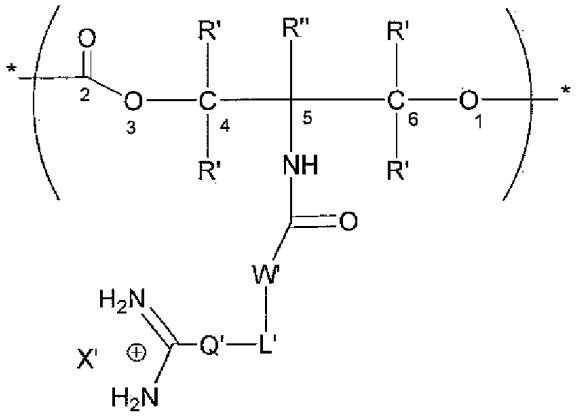
[0011] Further disclosed is a method of killing a microbe, comprising contacting the microbe with an above-described particle.

[0011a] In another aspect, there is provided an in vitro method of killing a microbe, comprising contacting the microbe with the particle as defined above, wherein the microbe is a Gram-positive microbe, Gram-negative microbe, and/or a fungus.

[0012] In another aspect, there is provided an antimicrobial composition comprising the cationic polymer as defined above and at least one other chemical component. Examples of antimicrobial compositions include soaps, shampoos, skin lotions, skin creams, cosmetics, mouthwashes, wound care agents, deodorants, surface cleaning agents, and laundry detergents.

[0013] Additionally disclosed is an antimicrobial cationic polycarbonate, comprising:

a cationic repeat unit of formula (A-4):



(A-4),

wherein

atoms 1-6 are backbone atoms of the cationic polycarbonate,

L' is a divalent hydrocarbon radical comprising 2 to 30 carbons,

Q' is *-N(H)-* or *-S-*,

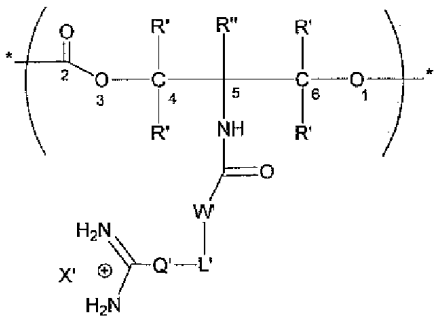
R' is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

R'' is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

X' is a negative-charged counterion, and

W' is a single bond, *-O-*, or *-N(H)-*.

[0013a] In another aspect, there is provided an antimicrobial cationic polycarbonate, comprising: a cationic subunit of formula (A-4):



(A-4),

wherein

atoms 1-6 are backbone atoms of the cationic polycarbonate,

L' is a divalent hydrocarbon radical comprising 2 to 30 carbons,

Q' is *-N(H)-* or *-S-*,

R' is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

R" is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

X' is a negative-charged counterion,

W' is a single bond, *-O-*, or *-N(H)-*,

and the degree of polymerization is in the range of from 5 to 20,

wherein the cationic polycarbonate has a structure in accordance with formula (B-1):

$$Z'\text{-}P'\text{-}Z'' \qquad (B\text{-}1),$$

wherein

Z' is a monovalent first end group comprising 1 to 40 carbons,

Z" is a monovalent second end group selected from the group consisting of hydrogen and groups comprising 1 to 40 carbons, and

P' is a polymer chain comprising the cationic subunit of formula (A-1);

or the cationic polycarbonate has a structure in accordance with formula (B-2):

$$Z^b\text{-}P^b\text{-}C'\text{-}P^b\text{-}Z^b \qquad (B\text{-}2),$$

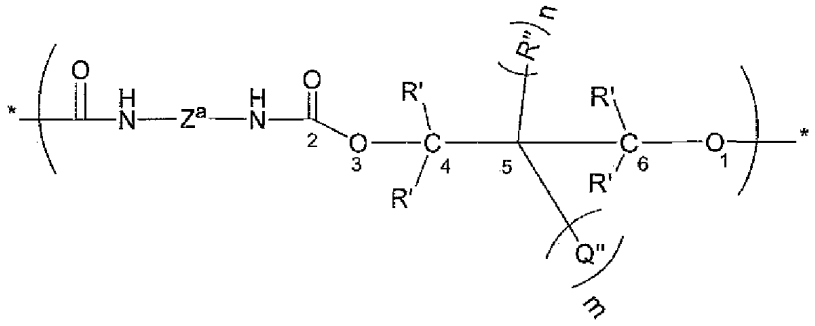
wherein

each P^b is an independent polymer chain comprising the cationic subunit of formula (A-1),

C' is a divalent linking group (core group) comprising 2 to 25 carbons, wherein C' comprises two heteroatoms independently selected from the group consisting of nitrogen, oxygen, and sulfur, wherein the heteroatoms are covalently linked to respective polymer chains P^b, and each Z^b is an independent monovalent end group selected from the group consisting of hydrogen and groups comprising 1 to 40 carbons.

[0014] In another aspect, there is provided an antimicrobial cationic polyurethane, comprising:

a cationic repeat unit according to formula (U-1):



(U-1),

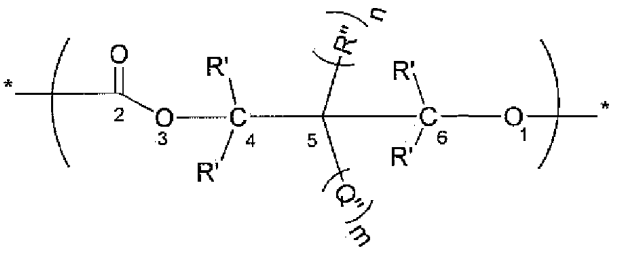
wherein

m is integer having a value of 1 or 2,

CLAIMS

What is claimed is:

1. An antimicrobial cationic polymer, comprising a cationic subunit of formula (A-1):



(A-1),

wherein

atoms 1-6 are backbone atoms of the cationic polymer,

m is 1 or 2,

n is 0 or 1, wherein when m is 2, n is 0,

each R' is an independent monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

R" is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

each Q^+ is an independent group comprising a guanidinium and/or isothiouronium group, and the degree of polymerization is in the range of from 5 to 20,

wherein the cationic polymer has a structure in accordance with formula (B-1):

Z'-P'-Z" (B-1),

wherein

Z' is a monovalent first end group comprising 1 to 40 carbons,

Z" is a monovalent second end group selected from the group consisting of hydrogen and groups comprising 1 to 40 carbons, and

P' is a polymer chain comprising the cationic subunit of formula (A-1);

or

the cationic polymer has a structure in accordance with formula (B-2):

$$Z^b\text{-}P^b\text{-}C'\text{-}P^b\text{-}Z^b \qquad \text{(B-2)},$$

wherein

each P^b is an independent polymer chain comprising the cationic subunit of formula (A-1),

C' is a divalent linking group (core group) comprising 2 to 25 carbons, wherein C' comprises two heteroatoms independently selected from the group consisting of nitrogen, oxygen, and sulfur, wherein the heteroatoms are covalently linked to respective polymer chains P^b, and

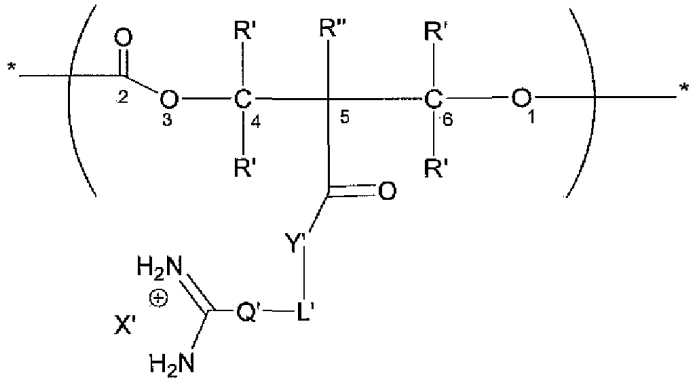
each Z^b is an independent monovalent end group selected from the group consisting of hydrogen and groups comprising 1 to 40 carbons.

2. The cationic polymer of claim 1, wherein the cationic polymer is selected from the group consisting of polycarbonates and polyurethanes.

3. The cationic polymer of claim 1, wherein the cationic polymer is capable of killing a Gram-positive bacterium, a Gram-negative bacterium, and/or a fungus.

4. The cationic polymer of claim 1, wherein m is 1 and n is 1.

5. The cationic polymer of claim 1, wherein the cationic subunit has a structure according to formula (A-2):



(A-2),

wherein

atoms 1-6 are backbone atoms of the cationic polymer,

L' is a divalent hydrocarbon radical comprising 2 to 30 carbons,

Q' is *-N(H)-* or *-S-*,

each R' is an independent monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

R" is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

X' is a negative-charged counterion, and

Y' is *-O-* or *-N(H)-* or

wherein L' is selected from the group consisting of 1,2-ethylene, 1,3-propylene, 1,4-butylene, 1,5-pentylene, 1,4-cyclohexylene, and 1,4-phenylene or

wherein Q' is *-N(H)-* or

-S- or

wherein Y' is *-O-* or

wherein R" is methyl or ethyl.

6. The cationic polymer of claim 5, wherein X' is a negative-charged counterion selected from the group consisting of chloride, bromide, iodide, acetate, benzoate, trifluoroacetate, hydrogen carbonate, methansulfonate, hydrogen sulfate, and dihydrogen phosphate.

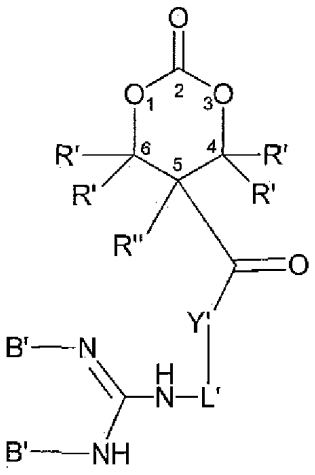
7. The cationic polymer of claim 1, wherein P' is a polycarbonate or

a polyurethane.

8. An in vitro method of killing a microbe, comprising contacting the microbe with the cationic polymer of claim 1.

9. A method of forming the cationic polymer of claim 1, comprising:

forming an initial polymer by organocatalyzed ring opening polymerization of a cyclic carbonate monomer of formula (M-1):



(M-1),

wherein

ring atoms are numbered 1 to 6,

each B' is an independent acid-labile protecting group,

L' is a divalent hydrocarbon radical comprising 2 to 30 carbons,

each R' is an independent monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

R" is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons, and

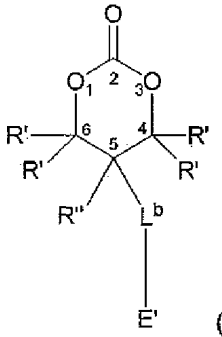
Y' is *-O-* or *-N(H)-*; and

treating the initial polymer with a protic acid, thereby forming the cationic polymer or

wherein each R' is hydrogen and R" is methyl or ethyl.

10. A method of forming the cationic polymer of claim 1, comprising:

forming an initial polymer by organocatalyzed ring opening polymerization of a cyclic carbonate monomer of formula (M-6):



(M-6),

wherein

the ring atoms are shown numbered 1 to 6,

L^b is a divalent linking group comprising 1 or more carbons,

E' is a substituent capable of undergoing a nucleophilic substitution reaction with thiourea to form an isothiouronium group,

each R' is an independent monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons, and

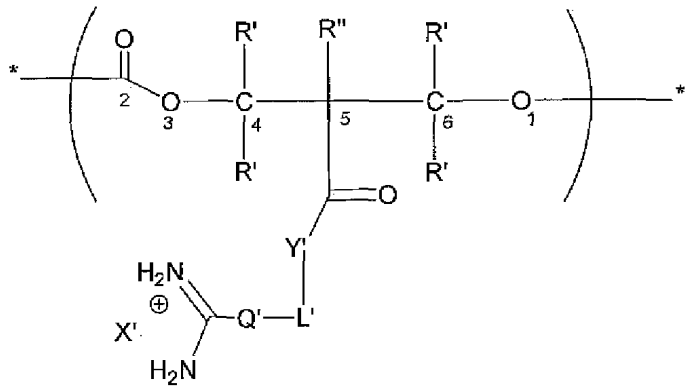
R" is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons; and

treating the initial polymer with thiourea, thereby forming the cationic polymer.

11. An antimicrobial particle, comprising:

a core comprising silica; and

a plurality of independent surface groups covalently linked to the core, wherein one or more of the surface groups comprises one or more cationic subunits of formula (A-2):



(A-2),

wherein

atoms 1-6 are backbone atoms of the surface groups,

L' is a divalent hydrocarbon radical comprising 2 to 30 carbons,

Q' is *-N(H)-* or *-S-*,

each R' is an independent monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

R" is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

X' is a negative-charged counterion, and

Y' is *-O-* or *-N(H)-*.

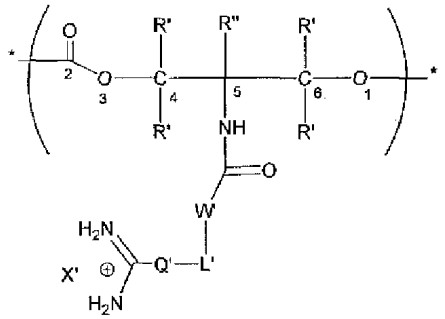
12. An in vitro method of killing a microbe, comprising contacting the microbe with the particle of claim 11, wherein the microbe is a Gram-positive microbe, Gram-negative microbe, and/or a fungus.

13. An antimicrobial composition comprising the cationic polymer of claim 1 and at least one other chemical component.

14. The antimicrobial composition of claim 13, wherein the antimicrobial composition is selected from the group consisting of soaps, shampoos, skin lotions, skin creams, cosmetics, mouthwashes, wound care agents, deodorants, surface cleaning agents, and laundry detergents.

15. An antimicrobial cationic polycarbonate, comprising:

a cationic subunit of formula (A-4):



(A-4),

wherein

atoms 1-6 are backbone atoms of the cationic polycarbonate,

L' is a divalent hydrocarbon radical comprising 2 to 30 carbons,

Q' is *-N(H)-* or *-S-*,

R' is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

R" is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

X' is a negative-charged counterion,

W' is a single bond, *-O-*, or *-N(H)-*,

and the degree of polymerization is in the range of from 5 to 20,

wherein the cationic polycarbonate has a structure in accordance with formula (B-1):

Z'-P'-Z" (B-1),

wherein

Z' is a monovalent first end group comprising 1 to 40 carbons,

Z'' is a monovalent second end group selected from the group consisting of hydrogen and groups comprising 1 to 40 carbons, and

P' is a polymer chain comprising the cationic subunit of formula (A-1);

or

the cationic polycarbonate has a structure in accordance with formula (B-2):

$$Z^b\text{-}P^b\text{-}C'\text{-}P^b\text{-}Z^b \qquad \text{(B-2)},$$

wherein

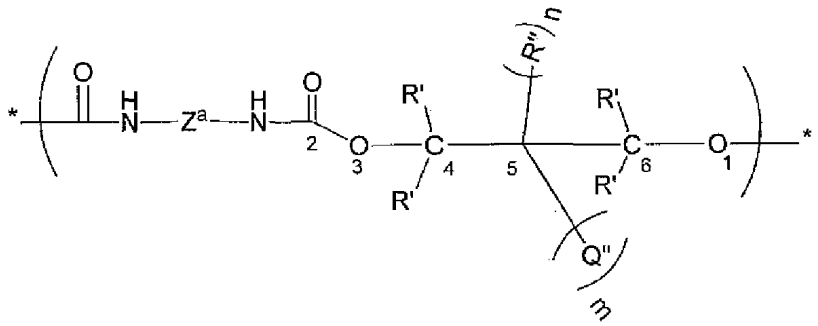
each P^b is an independent polymer chain comprising the cationic subunit of formula (A-1),

C' is a divalent linking group (core group) comprising 2 to 25 carbons, wherein C' comprises two heteroatoms independently selected from the group consisting of nitrogen, oxygen, and sulfur, wherein the heteroatoms are covalently linked to respective polymer chains P^b, and

each Z^b is an independent monovalent end group selected from the group consisting of hydrogen and groups comprising 1 to 40 carbons.

16. An antimicrobial cationic polyurethane, comprising:

a cationic repeat unit according to formula (U-1):



(U-1),

wherein

m is integer having a value of 1 or 2,

n is 0 or 1, wherein when m is 2, n is 0,

each R' is an independent monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

R" is a monovalent radical selected from the group consisting of hydrogen and alkyl groups comprising 1 to 6 carbons,

Z^a is a divalent hydrocarbon radical comprising 2 to 20 carbons, and

each Q" is an independent group comprising a guanidinium and/or isothiouronium group.

17. The cationic polyurethane of claim 16, wherein each Q" has a structure according to formula (U-2):

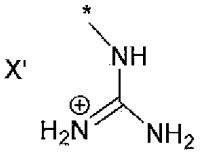
$*\text{-}L^5\text{-}G^5$ (U-2),

wherein

L^5 is a single bond or a divalent linking group comprising 1 to 10 carbons, wherein L^5 is linked to carbon 5 of formula (U-1), and

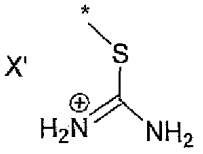
each G^5 comprises a guanidinium and/or isothiouronium group.

18. The cationic polyurethane of claim 16, wherein G^5 is



where each X' is a negative-charged counterion.

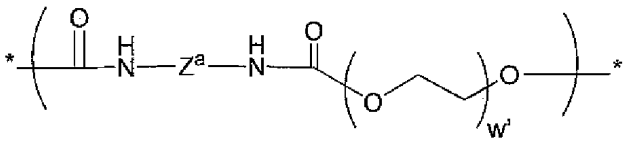
19. The cationic polyurethane of claim 16, wherein G^5 is



where each X' is a negative-charged counterion.

20. The cationic polyurethane of claim 16, comprising:

a second urethane-containing repeat unit of formula (U-3):



(U-3),

wherein

w' is integer having an average value of 1 to 100, and

Z^a is a divalent hydrocarbon radical comprising 2 to 20 carbons.