group that binds the metal species; and wherein the precipitant comprises at least one group that binds the metal species and/or the polymer, and at least one hydrophobic moiety.

[0014] A second aspect of the present disclosure provides use of a polymer comprising ionisable groups, a ligand, and a precipitant, to remove a metal species from a solution, wherein the solution comprises the metal species and a solvent; wherein the ionisable groups of the polymer are basic and the ligand comprises at least one acidic group, or wherein the ionisable groups of the polymer are acidic and the ligand comprises at least one basic group; wherein the ligand comprises at least one group that binds the metal species; and wherein the precipitant comprises at least one group that binds the metal species and/or the polymer and further comprises at least one hydrophobic moiety.

[0015] A third aspect of the present disclosure provides use of a salt to remove a metal species from a solution, wherein the solution comprises the metal species and a solvent, wherein the salt comprises:

(a) a cation of a polymer comprising basic ionisable groups and an anion of a ligand comprising at least one acidic group; or

(b) an anion of a polymer comprising acidic ionisable groups and a cation of a ligand comprising at least one basic group;

wherein the ligand comprises at least one group capable of binding a metal species.

[0016] The present disclosure provides a salt comprising a cation of a polymer comprising basic ionisable groups and an anion of a ligand; wherein the basic ionisable groups of the polymer are N-containing groups, preferably amine groups; and wherein the ligand comprises a C_1-C_{12} alkyl and: (i) at least one carboxyl group, sulfonic acid or phosphonate group, and (ii) at least one thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, amine, or a combination thereof; or wherein the ligand comprises a N-heterocycle containing 1 to 5 carbon atoms, and at least one thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, alcohol, ether, ester, ketone, carboxylic acid, or a combination thereof.

[0017] The present disclosure provides a salt comprising an anion of a polymer comprising acidic ionisable groups and a cation of a ligand; wherein the acidic ionisable groups of the polymer are carboxyl groups or sulfonic acid groups; and wherein the ligand comprises a C_1-C_{12} alkyl and: (i) at least one N-containing group, and (ii) at least one thiol, thioether, thioester, thioamide, amine, phosphonic acid group, or a combination thereof; or wherein the ligand comprises a N-heterocycle containing 1 to 5 carbon atoms, and at least one thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, alcohol, ether, ester, ketone, carboxylic acid, or a combination thereof.

[0017a] A fourth aspect of the present disclosure provides a salt comprising:

a. a cation of a polymer comprising basic ionisable groups and an anion of a ligand; wherein the basic ionisable groups of the polymer are N-containing groups; and

wherein the ligand comprises a C_1-C_{12} alkyl and: (i) at least one carboxyl group, sulfonic acid or phosphonate group, and (ii) at least one thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, amine, or a combination thereof; or
wherein the ligand comprises a N-heterocycle containing 1 to 5 carbon atoms, and at least one thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, alcohol, ether, ester, ketone, carboxylic acid, or a combination thereof;

or

b. an anion of a polymer comprising acidic ionisable groups and a cation of a ligand; wherein the acidic ionisable groups of the polymer are carboxyl groups or sulfonic acid groups; and wherein the ligand comprises a C_1-C_{12} alkyl and: (i) at least one N-containing group, and (ii) at least one thiol, thioether, thioester, thioamide, amine, phosphonic acid group, or a combination thereof; or wherein the ligand comprises a N-heterocycle containing 1 to 5 carbon atoms, and at least one thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, alcohol, ether, ester, ketone, carboxylic acid, or a combination thereof.

[0018] The present disclosure provides a composition comprising the salt as defined herein.

[0018a] A fifth aspect of the present disclosure provides a composition comprising the salt as defined herein, preferably wherein the composition is an aqueous solution comprising said salt.

[0019] The present disclosure provides a product comprising (a) a complex comprising: (i) a cation of a polymer comprising basic ionisable groups and an anion of a ligand comprising at least one acidic group; or an anion of a polymer comprising acidic ionisable groups and a cation of a ligand

comprising at least one basic group; and (ii) a metal species; and (b) a precipitant, wherein the ligand comprises at least one group capable of binding a metal species and the metal species is bound to said at least one group; and wherein the precipitant comprises at least one group that is bound to the metal species and/or the polymer and further comprises at least one hydrophobic moiety.

[0019a] A sixth aspect of the present disclosure is a product comprising (a) a complex comprising: (i) a cation of a polymer comprising basic ionisable groups and an anion of a ligand comprising at least one acidic group; or an anion of a polymer comprising acidic ionisable groups and a cation of a ligand comprising at least one basic group; and (ii) a metal species; and (b) a precipitant, wherein the ligand comprises at least one group capable of binding a metal species and the metal species is bound to said at least one group; and wherein the precipitant comprises at least one group that is bound to the metal species and/or the polymer and further comprises at least one hydrophobic moiety, preferably wherein the complex of polymer, ligand and metal species, and the precipitant, together form a polymer-ligand-metal species-precipitant aggregate.

[0020] These aspects and embodiments thereof are set out in the appended independent and dependent claims. It will be appreciated that features of the dependent claims may be combined with each other and with features of the independent claims in combinations other than those explicitly set out in the claims. Furthermore, the approaches described herein are not restricted to specific embodiments such as those set out below, but include and contemplate any combinations of features presented herein. In this respect, the disclosure is intended to be read holistically, such that any separate features or elements in any of the various aspects and embodiments should be viewed as combinable unless the context clearly dictates otherwise.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1: Figure 1 is a key for understanding the remaining figures.

Figure 2: Figure 2 is a schematic representation of a polymer with ionisable groups.

Figure 3: Figure 3 is a schematic representation of a salt formed between the polymer with ionisable groups and the ligand.

Figure 4: Figure 4 is a schematic representation of a complex formed between the polymer with ionisable groups, the ligand, and the metal species in solution.

Figure 5: Figure 5 is a schematic representation of an aggregate formed between the polymer with ionisable groups, the ligand, and the metal species in solution, and a precipitant. The aggregate depicted is expected to be a reasonable representation of the obtained flocculated product.

[0021] The drawings are exemplary only and should not be construed as limiting the disclosure.

DETAILED DESCRIPTION

[0022] While various exemplary embodiments are described or suggested herein, other exemplary embodiments utilizing a variety of methods and materials similar or equivalent to those described or suggested herein are encompassed by the general inventive concepts. Those aspects and features of embodiments that are implemented conventionally may not be discussed or described in detail in the interests of brevity. It will thus be appreciated that aspects and features of apparatus and methods described herein which are not described in detail may be implemented in accordance with any conventional techniques for implementing such aspects and features.

[0023] As used in this specification and the claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. Unless otherwise stated, the term "about" modifying the quantity of a component refers to variation in the numerical quantity that can occur, for

CLAIMS

1. A process for removing a metal species from a solution, wherein the solution comprises the metal species and a solvent, which process comprises treating the solution with a polymer comprising ionisable groups, and a ligand, to form a complex; and treating the solution with a precipitant;
wherein the ionisable groups of the polymer are basic and the ligand comprises at least one acidic group, or wherein the ionisable groups of the polymer are acidic and the ligand comprises at least one basic group;
wherein the ligand comprises at least one group that binds the metal species;
and wherein the precipitant comprises at least one group that binds the metal species and/or the polymer, and at least one hydrophobic moiety.

2. The process of claim 1, wherein the ligand electrostatically binds the polymer; and/or
wherein the complex comprises:
- a positively charged species formed from the polymer and a negatively charged species formed from the ligand, or a negatively charged species formed from the polymer and a positively charged species formed from the ligand; and
- the metal species.

3. The process according to claim 1 or 2, wherein the process comprises:
mixing the polymer with the ligand to form a salt; wherein the salt comprises a positively charged species formed from the polymer and a negatively charged species formed from the ligand, or a negatively charged species formed from the polymer and a positively charged species formed from the ligand; or
wherein the process comprises:
(i) mixing the polymer with the ligand to form a salt; wherein the salt comprises a positively charged species formed from the polymer and a negatively charged species formed from the ligand, or a negatively charged species formed from the polymer and a positively charged species formed from the ligand; and
(ii) treating the solution comprising the metal species and the solvent with the salt formed in step (i) to form the complex as defined in claim 1; and treating the solution with the precipitant;
preferably wherein the salt is in the liquid phase; and/or
wherein treating with the precipitant causes the complex to precipitate from the solution.

4. The process according to any preceding claim, wherein the metal species is selected from noble metal species, preferably wherein the metal species is selected from platinum group metal species, copper species, gold species, silver species, or a combination thereof; and/or
wherein the metal species is a metallic ion, preferably wherein the metal species is a metallic cation.

5. The process according to any preceding claim, wherein the ionisable groups of the polymer are basic and the ligand comprises at least one acidic group, preferably wherein the ionisable groups of the polymer are N-containing groups; and/or
wherein the polymer comprises polyethyleneimine, polyvinylamine, polyallylamine, chitosan, polylysine, polyarginine, or a combination thereof; and/or
wherein the at least one acidic group of the ligand is selected from carbon-based acids, sulfur-based acids, phosphorus-based acids, or a combination thereof,
preferably wherein the at least one acidic group of the ligand is selected from a carboxyl group, a sulfonic acid group, a phosphoric acid group, a phosphinic acid group, and a phosphonic acid group.

6. The process according to any one of claims 1 to 4, wherein the ionisable groups of the polymer are acidic and the ligand comprises at least one basic group, preferably wherein the ionisable groups of the polymer are selected from carboxyl groups, sulfonic acid groups, phosphoric acid groups, phosphinic acid groups, phosphonic acid groups, or a combination thereof; and/or wherein the polymer comprises monomeric units which are aliphatic or aromatic hydrocarbons, and wherein the ionisable groups are carboxyl groups or sulfonic acid groups; and/or
wherein the polymer comprises poly(meth)acrylic acid, polyaspartic acid, polyglutamic acid, alginic acid, polyvinylsulfonic acid, polyphosphoric acid, or a combination thereof, and
wherein the at least one basic group of the ligand is a N-containing group.

7. The process according to any preceding claim, wherein the at least one group that binds the metal species comprises at least one sulfur atom, phosphorus atom, nitrogen atom, oxygen atom, or a combination thereof, preferably wherein the at least one group that binds the metal species comprises at least one thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, phosphine, phosphite, phosphate, amine, imine, amide, N-heterocycle, alcohol, ether, ester, ketone, carboxylic acid, or a combination thereof; and/or wherein the ligand comprises (i) a C_1-C_{12} hydrocarbyl, and (ii) at least one amine group and at least one thioyl or phosphonate group; at least two amine groups; at least two carboxylic acids; or at least one carboxylic acid and at least one amine, thiol, thioether, thioamide, thioester, dithiocarbamate, thionyl or phosphonate group; or wherein the ligand comprises a C_1-C_{10} heteroaryl, and at least one thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, amine, imine, amide, alcohol, ether, ester, ketone, carboxylic acid, or a combination thereof, preferably
wherein the ligand comprises (i) a C_1-C_{12} alkyl and (ii) at least one amine group and at least one thioyl or phosphonate group; at least two amine groups; at least two carboxylic acids; or at least one carboxylic acid and at least one amine, thiol, thioether, thioamide, thioester, dithiocarbamate, thionyl or phosphonate group; or wherein the ligand comprises a N-

heterocycle containing 1 to 5 carbon atoms, and at least one thiol, thioether, thioester, dithiocarbamate, thienyl, ester, ketone, carboxylic acid, or a combination thereof; and/or wherein the precipitant is a surfactant or a polymer with ionisable groups, the ionisable groups being of opposite charge to the complex-forming polymer with ionisable groups defined in claim 1, preferably

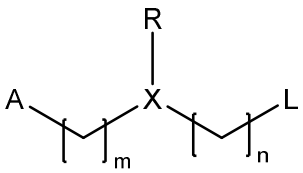
wherein:

(i) the ionisable groups of the polymer are basic, and the precipitant is selected from an anionic surfactant, a cationic surfactant, a polymer with at least one acidic group, and mixtures thereof; or

(ii) the ionisable groups of the polymer are acidic, and the precipitant is selected from an anionic surfactant, a cationic surfactant, a polymer with at least one basic group, and mixtures thereof.

8. The process according to any preceding claim, wherein:

- the metal species is selected from platinum group, gold and silver metal species;
- the ionisable groups of the polymer are basic N-containing groups;
- the ligand comprises a C_1-C_{12} alkyl and: (i) at least one carboxyl group or sulfonic acid group, and (ii) at least one thiol, thioether, thioester, thioamide, phosphonate, dithiocarbamate, thionyl, amine, or a combination thereof; or the ligand comprises a N-heterocycle containing 1 to 5 carbon atoms, and at least one thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, alcohol, ether, ester, ketone, carboxylic acid, or a combination thereof; and
- the precipitant is selected from an anionic surfactant, a cationic surfactant, and mixtures thereof, preferably wherein the ligand has the formula:

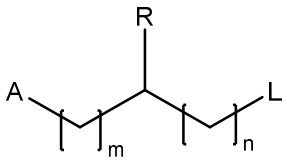


wherein n is 0 to 5; m is 1 to 5; L is a carboxyl group or an amine; A is selected from thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, phosphonate and amine; X is C or N; and R is selected from hydrogen, C_{1-5} alkyl, thiol, thioether, thioester, thioamide, dithiocarbamate, thienyl, and amine, provided that when X is N, R is hydrogen or C_{1-5} alkyl, or

wherein:

- the metal species is a copper species;
- the ionisable groups of the polymer are basic N-containing groups or acidic S-containing groups;

- the ligand comprises a C_1-C_{12} alkyl and: (i) at least one carboxyl group, sulfonic acid or phosphonate group, and (ii) at least one thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, amine, or a combination thereof; or the ligand comprises a N-heterocycle containing 1 to 5 carbon atoms, and at least one thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, or a combination thereof; and
- the precipitant is selected from an anionic surfactant, a cationic surfactant, a polymer with ionisable groups, the ionisable groups being of opposite charge to the basic N-containing groups or acidic S-containing groups of the polymer with ionisable groups, and mixtures thereof, preferably wherein the ligand has the formula:



wherein n is 0 to 5; m is 1 to 5; L is a carboxyl group or an amine; A is selected from thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, and phosphonate; and R is selected from hydrogen, thiol, thioether, thioester, thioamide, dithiocarbamate, and thionyl.

9. Use of a polymer comprising ionisable groups, a ligand, and a precipitant, to remove a metal species from a solution, wherein the solution comprises the metal species and a solvent;

wherein the ionisable groups of the polymer are basic and the ligand comprises at least one acidic group, or wherein the ionisable groups of the polymer are acidic and the ligand comprises at least one basic group;

wherein the ligand comprises at least one group that binds the metal species; and

wherein the precipitant comprises at least one group that binds the metal species and/or the polymer and further comprises at least one hydrophobic moiety.

10. Use of a salt to remove a metal species from a solution, wherein the solution comprises the metal species and a solvent, wherein the salt comprises:

a. a cation of a polymer comprising basic ionisable groups and an anion of a ligand comprising at least one acidic group; or

b. an anion of a polymer comprising acidic ionisable groups and a cation of a ligand comprising at least one basic group;

wherein the ligand comprises at least one group capable of binding the metal species.

11. The use according to claim 10, wherein the molar ratio of the monomer units of the polymer to the ligand is from about 1:4 to about 8:1; and/or wherein the salt further comprises a metal

species, preferably wherein the metal species is bound to the at least one group of the ligand capable of binding a metal species.

12. A salt comprising:

    a. a cation of a polymer comprising basic ionisable groups and an anion of a ligand; wherein the basic ionisable groups of the polymer are N-containing groups; and wherein the ligand comprises a C_1-C_{12} alkyl and: (i) at least one carboxyl group, sulfonic acid or phosphonate group, and (ii) at least one thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, amine, or a combination thereof; or wherein the ligand comprises a N-heterocycle containing 1 to 5 carbon atoms, and at least one thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, alcohol, ether, ester, ketone, carboxylic acid, or a combination thereof;

or

    b. an anion of a polymer comprising acidic ionisable groups and a cation of a ligand; wherein the acidic ionisable groups of the polymer are carboxyl groups or sulfonic acid groups; and wherein the ligand comprises a C_1-C_{12} alkyl and: (i) at least one N-containing group, and (ii) at least one thiol, thioether, thioester, thioamide, amine, phosphonic acid group, or a combination thereof; or wherein the ligand comprises a N-heterocycle containing 1 to 5 carbon atoms, and at least one thiol, thioether, thioester, thioamide, dithiocarbamate, thionyl, alcohol, ether, ester, ketone, carboxylic acid, or a combination thereof.

13. The salt according to claim 12, wherein the molar ratio of the monomer units of the polymer to the ligand is from about 1:4 to about 8:1; and/or wherein the salt further comprises a metal species, preferably wherein the metal species is bound to at least one group of the ligand.

14. A composition comprising the salt according to any of claims 12 to 13, preferably wherein the composition is an aqueous solution comprising said salt.

15. A product comprising:

    a. a complex comprising:
        i. a cation of a polymer comprising basic ionisable groups and an anion of a ligand comprising at least one acidic group; or an anion of a polymer comprising acidic ionisable groups and a cation of a ligand comprising at least one basic group; and
        ii. a metal species; and
    b. a precipitant;

wherein the ligand comprises at least one group capable of binding a metal species and the metal species is bound to said at least one group; and wherein the precipitant comprises at least one group that is bound to the metal species and/or the polymer and further comprises

at least one hydrophobic moiety; preferably wherein the complex of polymer, ligand and metal species, and the precipitant, together form a polymer-ligand-metal species-precipitant aggregate.