CLAIMS

1. A method for treating a crude oil to reduce its mercury level, comprising:

a) converting at least a portion of mercury in the crude oil to water soluble mercuric iodide in an oil-water emulsion upon contact with a molecular iodine source; and

b) separating the water containing the soluble mercuric iodide from the crude oil for a treated crude oil having a reduced concentration of mercury.

2. The method of claim 1, wherein the crude oil is brought into contact with the molecular iodine source by routing the crude oil through a bed containing solid iodine.

3. The method of claim 1, wherein the crude oil is brought into contact with the molecular iodine source by mixing the crude oil with a solution containing iodine in a solvent selected from methanol, naphtha, diesel, gasoline, mercury-free crude oil, and mixtures thereof.

4. The method of claim 1, wherein the contact is carried out in a pipeline for transporting crude oil, and wherein the molecular iodine source is continuously or intermittently fed into the crude oil pipeline.

5. The method of claim 1, wherein the contact is carried out in a vessel containing crude oil.

6. The method of claim 1, wherein the crude oil is brought into contact with the molecular iodine source by sparging an iodine-containing gas into the crude oil.

7. The method of claim 6, wherein the iodine-containing gas stream is formed by contacting a solid iodine source with a gas stream.

8. The method of claim 1, wherein the molecular iodine source is generated in-situ in an oxidation-reduction reaction between an iodine species having a charge and a reagent which functions as a reductant or an oxidant depending on the charge of the iodine species.

9. The method of any of claims 1 - 8, wherein the molar ratio of iodine to mercury in the crude oil ranges from 1:1 to 30,000:1.

10. The method of any of claims 1 - 8, wherein the molar ratio of iodine to mercury in the crude oil ranges from 2:1 to 10,000:1.

11. A method for treating a crude oil to reduce its mercury level, comprising:

a) providing a reagent and an iodine species having a charge;

b) mixing the reagent and the iodine species with the crude oil containing mercury, wherein molecular iodine is generated in-situ in the crude oil in an oxidation-reduction reaction between the iodine species having a charge and the reagent to convert at least a portion of the mercury to water soluble mercuric iodide in an oil-water emulsion; and

c) separating the water containing the water soluble mercuric iodide from the crude oil for a treated crude oil having a reduced concentration of mercury.

12. The method of claim 11, wherein at least 50% of the molecular iodine is generated in-situ within 10 minutes from mixing the iodine species having a charge and the reagent.

13. The method of any of claims 11 - 12, wherein the iodine species having a charge is positively charged, and the reagent functions as a reducing agent.

14. The method of any of claims 11 - 12, wherein the iodine species having a charge is negatively charged, and the reagent functions as an oxidizing agent.

15. The method of claim 13, wherein the positively charged iodine species is selected from the group of periodic acid (H_5IO_6), potassium periodate (KIO_4), sodium periodate ($NaIO_4$), iodic acid (HIO_3), potassium iodate (KIO_3), potassium hydrogen iodate (KHI_2O_6), sodium iodate ($NaIO_3$), iodine oxide (I_2O_5), iodine trichloride (ICl_3), iodine monobromide (IBr), and iodine monochloride (ICl).

16. The method of claim 13, wherein the reagent functioning as a reducing agent is selected from the group of thioureas, thiols, thiosulfates, ascorbates, imidazoles, and mixtures thereof.

17. The method of claim 14, wherein the negatively charged iodine species is selected from the group of hydriodic acid (HI), sodium iodide (NaI), potassium iodide (KI), ammonium iodide (NH_4I), aluminum iodide (AlI_3), boron triodide (BI_3), calcium iodide (CaI_2), magnesium iodide (MgI_2), iodoform (CHI_3), tetraiodoethylene (C_2I_4), iodoethanol, iodoacetic anhydride ($(ICH_2CO)_2O$), iododecane ($CH_3(CH_2)_3I$), and iodobenzene.

18. A method for treating a crude oil to reduce its mercury level, comprising:

a) adding an effective amount of a reagent that functions as an oxidizing agent to the crude oil;

b) adding a negatively charged iodine species in an excess amount at a molar ratio of iodine to heavy metals of at least 2:1 to generate molecular iodine in-situ in the crude oil in an oxidation-reduction reaction between the negatively charged iodine species and the reagent, wherein the in-situ iodine converts mercury to cationic mercury in a water-oil emulsion and forms water soluble mercury complexes; and

c) separating the water containing the soluble mercury complexes from the crude oil for a treated crude oil having a reduced concentration of mercury.

19. The method of any of claims 14 and 18 wherein the reagent that functions as an oxidizing agent is selected from the group of peroxides, ozone (O_3), NaOCl, iodates, bromine, alkali metal salts of peroxide, alkaline earth metal salts of peroxide, monopersulfates, perborate, percarbonate, perchlorate, permanganate, perphosphate, peroxidases, and mixtures thereof.

20. The method of claim 18, wherein the reagent that functions as an oxidizing agent is hydrogen peroxide.

21. The method of any of claims 1 - 8, 11, and 18, wherein the treated crude oil contains less than 100 ppb mercury.

22. The method of any of claims 1 - 8, 11, and 18, wherein the treated crude oil contains less than 50 ppb mercury.

23. The method of any of claims 1 - 8, 11, and 18, wherein the treated crude oil contains less than 10 ppb mercury.

24. The method of any of claims 11 and 18, wherein the ratio of molecular iodine generated in-situ to starting iodine in the iodine species ranges from 0.5 to 1.

25. The method of any of claims 11 and 18, wherein the ratio of molecular iodine generated in-situ to starting iodine in the iodine species ranges from 0.8 to 1.

26. The method of claim 18, wherein the iodine species is selected from the group of RX and RX_2, wherein X is iodide and R is selected from potassium, lithium, sodium, calcium, magnesium, and ammonium.

27. A method for treating a crude oil to reduce its mercury level, comprising:

a) passing a stream of crude oil through a bed comprising molecular iodine to convert at least a portion of mercury in the crude oil to water soluble mercuric iodide in an oil-water emulsion phase; and

b) separating the water containing the mercuric iodide from the crude oil in a phase separation device for a treated crude oil having a reduced concentration of mercury.

28. The method of claim 27, wherein the treated crude oil has less than 50 ppb mercury.

29. A method for treating a crude oil to reduce its mercury level, comprising:

a) converting at least a portion of mercury in the crude oil to soluble mercuric iodide in a water phase upon contact with iodine in a solvent; and

b) separating the water containing the soluble mercuric iodide from the crude oil in a phase separation device for a treated crude oil having less than 50 ppb mercury.

30. The method of claim 29, wherein the solvent is selected from the group of methanol, diesel, naphtha, gasoline, mercury-free crude oil, and mixtures thereof.

31. A method for treating a crude oil to reduce its heavy metal level, comprising:

a) providing a reducing reagent and an iodine source containing an iodine species having a positive charge;

b) mixing the reducing reagent and the iodine source with the crude oil containing mercury, wherein molecular iodine is generated in-situ in the crude oil in an oxidation-reduction reaction between the iodine species having a positive charge and a reducing reagent, wherein the in-situ molecular iodine converts heavy metal to heavy metal cations;

b) contacting the heavy metal cations with a complexing agent to form a water soluble heavy metal compound in an oil-water emulsion; and

c) separating the water containing the soluble heavy metal compound from the crude oil for a treated crude oil having a reduced concentration of heavy metal.

32. The method of claim 31, wherein the heavy metal is mercury.

33. The method of any of claims 31 - 32, wherein at least 50% of the molecular iodine is generated in-situ within 10 minutes from contact between the iodine species having a positive charge and the reducing reagent.

34. The method of any of claims 31 - 32, wherein at least 75% of the molecular iodine is generated in-situ within 10 minutes from contact between the iodine species having a positive charge and the reducing reagent.

35. The method of any of claims 31 - 32, wherein the positively charged iodine species is selected from the group of periodic acid (H_5IO_6), potassium periodate (KIO_4), sodium periodate ($NaIO_4$), iodic acid (HIO_3), potassium iodate (KIO_3), potassium hydrogen iodate (KHI_2O_6), sodium iodate ($NaIO_3$), iodine oxide (I_2O_5), iodine trichloride (ICl_3), iodine monobromide (IBr), and iodine monochloride (ICl).

36. The method of any of claims 31 - 32, wherein the reducing reagent is selected from the group of thioureas, thiols, thiosulfates, ascorbates, imidazoles, and mixtures thereof.

37. The method of any of claims 31 - 32, wherein the reducing reagent is selected from the group of sulfides, ammonium thiosulfate, alkali metal thiosulfates, alkaline earth metal thiosulfates, iron thiosulfates, alkali metal dithionites, alkaline earth metal dithionites, and mixtures thereof.

38. The method of any of claims 31 - 32, wherein the complexing agent is a polyamine.

39. The method of any of claims 31 - 32, wherein the complexing agent is selected from the group of ethylenediamine, propylenediamine, triaminotriethylamine, diethylenetriamine, triethylenetetramine (TRIEN), tetra-2-aminoethylethlenediamine, tetraethylenepentamine (TETREN), ethylene-diamine-tetra-acetic acid (EDTA), nitrilotriacetic acid (NTA), and mixtures thereof.

40. The method of any of claims 31 - 32, wherein the ratio of molecular iodine generated in-situ to starting iodine in the iodine species ranges from 0.5 to 1.

41. A method for reducing a trace element of mercury in a crude oil, comprising:

a) adding an effective amount of an iodine containing species and a reducing agent to the crude oil to generate iodine in-situ, converting mercury to cationic mercury in a water-oil emulsion;

b) adding an effective amount of a complexing agent to the water-oil emulsion mixture to form soluble mercury complexes in a water phase; and

c) separating the water containing the soluble mercury complexes from the crude oil for a treated crude oil having a reduced concentration of mercury.

CLAIMS

1. A method for treating a crude oil to reduce its mercury level, comprising:

a) converting at least a portion of mercury in the crude oil to water soluble mercuric iodide in an oil-water emulsion upon contact with a molecular iodine source; and

b) separating the water containing the soluble mercuric iodide from the crude oil for a treated crude oil having a reduced concentration of mercury;

wherein crude oil is a natural liquid hydrocarbon product or a synthetic liquid hydrocarbon product selected from petroleum products, intermediate petroleum stream products and refined petroleum products.

2. The method of claim 1, wherein the crude oil is brought into contact with the molecular iodine source by routing the crude oil through a bed containing solid iodine.

3. The method of claim 1, wherein the crude oil is brought into contact with the molecular iodine source by mixing the crude oil with a solution containing iodine in a solvent selected from methanol, naphtha, diesel, gasoline, mercury-free crude oil, and mixtures thereof.

4. The method of claim 1, wherein the contact is carried out in a pipeline for transporting crude oil, and wherein the molecular iodine source is continuously or intermittently fed into the crude oil pipeline.

5. The method of claim 1, wherein the contact is carried out in a vessel containing crude oil.

6. The method of claim 1, wherein the crude oil is brought into contact with the molecular iodine source by sparging an iodine-containing gas into the crude oil.

7. The method of claim 6, wherein the iodine-containing gas stream is formed by contacting a solid iodine source with a gas stream.

8. The method of claim 1, wherein the molecular iodine source is

generated in-situ in an oxidation-reduction reaction between an iodine species having a charge and a reagent which functions as a reductant or an oxidant depending on the charge of the iodine species.

9. The method of any of claims 1 - 8, wherein the molar ratio of iodine to mercury in the crude oil ranges from 1:1 to 30,000:1.

10. The method of any of claims 1 - 8, wherein the molar ratio of iodine to mercury in the crude oil ranges from 2:1 to 10,000:1.

11. A method for treating a crude oil to reduce its mercury level, comprising:

a) providing a reagent and an iodine species having a charge;

b) mixing the reagent and the iodine species with the crude oil containing mercury, wherein molecular iodine is generated in-situ in the crude oil in an oxidation-reduction reaction between the iodine species having a charge and the reagent to convert at least a portion of the mercury to water soluble mercuric iodide in an oil-water emulsion; and

c) separating the water containing the water soluble mercuric iodide from the crude oil for a treated crude oil having a reduced concentration of mercury.

12. The method of claim 11, wherein at least 50% of the molecular iodine is generated in-situ within 10 minutes from mixing the iodine species having a charge and the reagent.

13. The method of any of claims 11 - 12, wherein the iodine species having a charge is positively charged, and the reagent functions as a reducing agent.

14. The method of any of claims 11 - 12, wherein the iodine species having a charge is negatively charged, and the reagent functions as an oxidizing agent.

15. The method of claim 13, wherein the positively charged iodine species is selected from the group of periodic acid (H_5IO_6), potassium periodate (KIO_4), sodium periodate ($NaIO_4$), iodic acid (HIO_3), potassium iodate (KIO_3), potassium hydrogen iodate (KHI_2O_6), sodium iodate ($NaIO_3$), iodine oxide (I_2O_5), iodine trichloride (ICl_3), iodine monobromide (IBr), and iodine monochloride (ICl).

16. The method of claim 13, wherein the reagent functioning as a reducing agent is selected from the group of thioureas, thiols, thiosulfates, ascorbates, imidazoles, and mixtures thereof.

17. The method of claim 14, wherein the negatively charged iodine species is selected from the group of hydriodic acid (HI), sodium iodide (NaI), potassium iodide (KI), ammonium iodide (NH_4I), aluminum iodide (AlI_3), boron triodide (BI_3), calcium iodide (CaI_2), magnesium iodide (MgI_2), iodoform (CHI_3), tetraiodoethylene (C_2I_4), iodoethanol, iodoacetic anhydride ($(ICH_2CO)_2O$), iododecane ($CH_3(CH_2)_3I$), and iodobenzene.

18. A method for treating a crude oil to reduce its mercury level, comprising:

a) adding an effective amount of a reagent that functions as an oxidizing agent to the crude oil;

b) adding a negatively charged iodine species in an excess amount at a molar ratio of iodine to mercury of at least 2:1 to generate molecular iodine in-situ in the crude oil in an oxidation-reduction reaction between the negatively charged iodine species and the reagent, wherein the in-situ iodine converts mercury to cationic mercury in a water-oil emulsion and forms water soluble mercury complexes; and

c) separating the water containing the soluble mercury complexes from the crude oil for a treated crude oil having a reduced concentration of mercury;

wherein the iodine species is selected from the group of RX and RX_2, wherein X is iodide and R is selected from potassium, lithium, sodium, calcium, magnesium, and ammonium.

19. The method of any of claims 14 and 18 wherein the reagent that functions as an oxidizing agent is selected from the group of peroxides, ozone (O_3), NaOCl, iodates, bromine, alkali metal salts of peroxide, alkaline earth metal salts of peroxide, monopersulfates, perborate, percarbonate, perchlorate, permanganate, perphosphate, peroxidases, and mixtures thereof.

20. The method of claim 18, wherein the reagent that functions as an oxidizing agent is hydrogen peroxide.

21. The method of any of claims 1 - 8, 11, and 18, wherein the treated crude oil contains less than 100 ppb mercury.

22. The method of any of claims 1 - 8, 11, and 18, wherein the treated crude oil contains less than 50 ppb mercury.

23. The method of any of claims 1 - 8, 11, and 18, wherein the treated crude oil contains less than 10 ppb mercury.

24. The method of any of claims 11 and 18, wherein the ratio of molecular iodine generated in-situ to starting iodine in the iodine species ranges from 0.5 to 1.

25. The method of any of claims 11 and 18, wherein the ratio of molecular iodine generated in-situ to starting iodine in the iodine species ranges from 0.8 to 1.

26. A method for treating a crude oil to reduce its mercury level, comprising:

a) passing a stream of crude oil through a bed comprising molecular iodine to convert at least a portion of mercury in the crude oil to water soluble mercuric iodide in an oil-water emulsion phase; and

b) separating the water containing the mercuric iodide from the crude oil in a phase separation device for a treated crude oil having a reduced concentration of mercury.

27. The method of claim 26, wherein the treated crude oil has less than 50 ppb mercury.

28. A method for treating a crude oil to reduce its mercury level, comprising:

a) converting at least a portion of mercury in the crude oil to soluble mercuric iodide in a water phase upon contact with iodine in a solvent; and

b) separating the water containing the soluble mercuric iodide from the crude oil in a phase separation device for a treated crude oil having less than 50 ppb mercury.

29. The method of claim 28, wherein the solvent is selected from the group of methanol, diesel, naphtha, gasoline, mercury-free crude oil, and mixtures thereof.

30. A method for treating a crude oil to reduce its heavy metal level, comprising:

a) providing a reducing reagent and an iodine source containing an iodine species having a positive charge;

b) mixing the reducing reagent and the iodine source with the crude oil containing mercury, wherein molecular iodine is generated in-situ in the crude oil in an oxidation-reduction reaction between the iodine species having a positive charge and a reducing reagent, wherein the in-situ molecular iodine converts heavy metal to heavy metal cations;

c) contacting the heavy metal cations with a complexing agent to form a water soluble heavy metal compound in an oil-water emulsion; and

d) separating the water containing the soluble heavy metal compound from the crude oil for a treated crude oil having a reduced concentration of heavy metal;

wherein the heavy metal is mercury.

31. A method for reducing a trace element of mercury in a crude oil, comprising:

a) adding an effective amount of an iodine containing species and a reducing agent to the crude oil to generate iodine in-situ, converting mercury to cationic mercury in a water-oil emulsion;

b) adding an effective amount of a complexing agent to the water-oil emulsion mixture to form soluble mercury complexes in a water phase; and

c) separating the water containing the soluble mercury complexes from the crude oil for a treated crude oil having a reduced concentration of mercury.