CLAIMS

1. A process for reducing the sulphur content of a hydrocarbon material containing sulphur compounds, the process comprising:

a) contacting the hydrocarbon material with one or more primary oxidants to provide a primary oxidised hydrocarbon material such that the primary oxidant oxidizes the sulphur compounds to sulphoxide and/or sulphone compounds,

wherein the primary oxidant is selected from one or more of the group consisting of N-chloroimide, hypobromous acid and electrolyzed oxidizing water;

b) contacting the primary oxidised hydrocarbon material with an extractant to allow at least a portion of the sulphoxide and/or sulphone compounds to be extracted into the extractant to give a sulphoxide and/or sulphone stream and a low sulphur hydrocarbon stream; and

c) separating the sulphoxide and/or sulphone stream from the low sulphur hydrocarbon stream.

2. The process according to claim 1 wherein the extractant is a polar extraction solvent selected from the group consisting of acetonitrile, DMF, DMSO, methanol, water, brine and furfural or an ionic liquid (IL).

3. The process according to claim 1 or 2 wherein the extractant is acetonitrile.

4. The process according to any one of claims 1 to 3 wherein the process further includes a step of contacting the sulphone and/or sulfoxide stream from step c) with a secondary oxidant to provide a secondary oxidised hydrocarbon material, wherein the secondary oxidant is selected from one or more of the group consisting of hydroxyl radicals, liquid ferrate (iron VI), chlorine dioxide and hypofluorous acid/ polar liquid solvent, such that the secondary oxidant oxidizes sulphur compounds to sulphoxide and/or sulphone compounds.

5. The process according to any one of claims 1 to 4 wherein the process further includes the step of contacting the sulphoxide and/or sulphone stream with a tertiary oxidant to give an aqueous sulphite stream and a low sulphur aromatic hydrocarbon stream, wherein the tertiary oxidant oxidises sulphone and/or sulphoxide compounds to sulphite compounds.

6. The process according to claim 4 wherein the process further includes a step of contacting the secondary oxidised hydrocarbon material with an extractant to allow at least a portion of the sulphoxide and/or sulphone compounds to be extracted into the extractant to give a sulphoxide and/or sulphone stream and a low sulphur hydrocarbon stream.

7. The process according to any one of claims 1 to 6 wherein the hydrocarbon material containing sulphur compounds has a sulphur mass of greater than 1000 ppm.

8. The process according to any one of claims 1 to 7 wherein the N-chloroimide is prepared by reaction of sodium hypochlorite, water and an imide.

9. The process according to claim 8 wherein the imide is cyanuric acid.

10. The process according to claim 7 or 8 wherein the N-chloroimide is prepared *in situ*.

11. The process according to any one of claims 1 to 10 wherein the primary oxidant is hypobromous acid prepared *in situ* by electrolysis of hydrogen bromide in water.

12. The process according to any one of claims 1 to 10 wherein the primary oxidant is electrolysed oxidising water.

13. The process according to any one of claims 1 to 12 wherein the hydrocarbon material is contacted with the primary oxidant in at least a stoichiometric amount for the conversion of sulphur compounds to sulphoxide and/or sulphone compounds.

14. The process according to any one of claims 1 to 13 wherein the hydrocarbon material is contacted with the primary oxidant at a temperature in the range of 20˚C to 70˚C and a pressure in the range of 140 kPa to 700 kPa, more preferably 20˚C to 40˚C and 210 kPa to 350 kPa.

15. The process according to any one of claims 1 to 14 wherein the secondary oxidant is contacted with the primary oxidised hydrocarbon material or the hydrocarbon material at a temperature of less than 35ºC, and at a pressure of less than 700 kPa, and for a period of time in the range of 30 seconds to 10 minutes.

16. The process according to any one of claims 1 to 15 wherein the secondary oxidant is chlorine dioxide, in the form of a stabilised water solution having a chlorine dioxide content in the range of 3000 ppm (0.3%) to 8000 ppm (0.8%).

17. The process according to any one of claims 1 to 16 wherein the secondary oxidant is chlorine dioxide which is supplied at a temperature in the range of 15 to 35 °C and at a pressure of 140 kPa to 700 kPa.

18. A process for reducing the sulphur content of a hydrocarbon material containing sulphur compounds, the process comprising:

a) contacting the hydrocarbon material with one or more primary oxidants to provide a primary oxidised hydrocarbon material such that the primary oxidant oxidizes the sulphur compounds to sulphoxide and/or sulphone compounds,

wherein the primary oxidant is selected from one or more of the group consisting of N-chloroimide, hypobromous acid, hypochlorous acid, electrolyzed oxidizing water and catalysed and co-catalysed hydrogen peroxide;

b) contacting the primary oxidised hydrocarbon material with an extractant to allow at least a portion of the sulphoxide and/or sulphone compounds to be extracted into the extractant to give a sulphoxide and/or sulphone stream and a low sulphur hydrocarbon stream;

c) separating the sulphoxide and/or sulphone stream from the low sulphur hydrocarbon stream; and

d) contacting the sulphoxide and/or sulphone stream from step c) with a secondary oxidant to provide a secondary oxidised hydrocarbon material, wherein the secondary oxidant is hypofluorous acid in acetonitrile, prepared by bubbling a gaseous mixture comprising fluorine and nitrogen into liquid acetonitrile to form $HOF.CH_3CN$, wherein the concentration of fluorine mixed with nitrogen does not exceed 20% by weight fluorine blended with the nitrogen,

such that the secondary oxidant oxidizes sulphur compounds to sulphoxide and/or sulphone compounds.

19. A process for reducing the sulphur content of a hydrocarbon material containing sulphur compounds, the process comprising the steps of:

a) contacting the hydrocarbon material with one or more primary oxidants to provide a primary oxidised hydrocarbon material such that the primary oxidant oxidizes the sulphur compounds to sulphoxide and/or sulphone compounds,

wherein the primary oxidant is catalysed and co-catalysed hydrogen peroxide and wherein the catalysed and co-catalysed hydrogen peroxide is hydrogen peroxide catalysed by phosphotungstic acid and co-catalysed with a phase transfer catalyst (PTC) comprising a quaternary ammonium salt, for example, a quarternary ammonium hydrogen sulphate;

b) contacting the primary oxidised hydrocarbon material with an extractant such as acetonitrile, to allow at least a portion of the sulphoxide and/or sulphone compounds to be extracted into the extractant to give a sulphoxide and/or sulphone stream and a low sulphur hydrocarbon stream;

c) separating the sulphoxide and/or sulphone stream from the low sulphur hydrocarbon stream; and

d) contacting the sulphoxide and/or sulphone stream from step c) with a secondary oxidant to provide a secondary oxidised hydrocarbon material, wherein the secondary oxidant is selected from one or more of the group consisting of hydroxyl radicals and hypofluorous acid in acetonitrile, prepared by bubbling a gaseous mixture comprising fluorine and nitrogen into liquid acetonitrile to form $HOF.CH_3CN$, wherein the concentration of fluorine mixed with nitrogen does not exceed 20% by weight fluorine blended with the nitrogen.

20. A process for reducing the sulphur content of a hydrocarbon material containing sulphur compounds, the process comprising the steps of:

a) contacting the hydrocarbon material with one or more primary oxidants to provide a primary oxidised hydrocarbon material such that the primary oxidant oxidizes the sulphur compounds to sulphoxide and/or sulphone compounds,

wherein the primary oxidant is catalysed and co-catalysed hydrogen peroxide and wherein the catalysed and co-catalysed hydrogen peroxide is hydrogen peroxide catalysed by phosphotungstic acid and co-catalysed with a phase transfer catalyst (PTC) comprising a quaternary ammonium salt, for example, a quarternary ammonium hydrogen sulphate;

b) contacting the primary oxidised hydrocarbon material and/or the secondary oxidised hydrocarbon material with an extractant, such as acetonitrile, to allow at least

a portion of the sulphoxide and/or sulphone compounds to be extracted into the extractant to give a sulphoxide and/or sulphone stream and a low sulphur hydrocarbon stream;

c) separating the sulphoxide and/or sulphone stream from the low sulphur hydrocarbon stream;

d) contacting the sulphoxide and/or sulphone stream from step c) with a secondary oxidant to provide a secondary oxidised hydrocarbon material, wherein the secondary oxidant is selected from one or more of the group consisting of hydroxyl radicals, and hypofluorous acid in acetonitrile, prepared by bubbling a gaseous mixture comprising fluorine and nitrogen into liquid acetonitrile to form $HOF.CH_3CN$, wherein the concentration of fluorine mixed with nitrogen does not exceed 20% by weight fluorine blended with the nitrogen,

such that the secondary oxidant oxidizes sulphur compounds to sulphoxide and/or sulphone compounds; and

e) contacting the sulphoxide and/or sulphone stream with a tertiary oxidant to give an aqueous sulphite stream and a low sulphur aromatic hydrocarbon stream, wherein the tertiary oxidant oxidises sulphone and/or sulphoxide compounds to sulphite compounds.

21. The process according to claim 19 or 20 wherein the secondary oxidant is supplied to a secondary oxidizing reactor at less than 25˚C (77˚F) and at a pressure in the range of 30 PSI (140 kPa) to 100 PSI (700 kPa).

22. The process of any one of claims 19 to 21 wherein the extractant is a polar extraction solvent selected from the group consisting of acetonitrile, DMF, DMSO, methanol, water, brine and furfural or an ionic liquid (IL).

23. The process according to any one of claims 19 to 22 wherein the primary and/or secondary oxidised hydrocarbon material obtained from step a) and/or step c) are washed with water.

24. The process according to any one of claims 1 to 23 further comprising a water washing step before the sulphoxide/sulphone stream and the low sulphur hydrocarbon stream are separated.

25. The process according to claim 5 or 20 wherein the tertiary oxidant is a caustic solution, selected from the group consisting of:

i) sodium hydroxide,

ii) potassium hydroxide and

iii) hydroxyl radicals.

26. The process according to claim 5, 20 or 25 wherein oxidation with the tertiary oxidant is carried out in a range of 40 to 95ºC.

27. The process according to claim 5, 20, 25 or 26 wherein the tertiary oxidant is sodium hydroxide and an aqueous sodium sulphite solution is formed.

28. The process according to claim 27 wherein the sodium hydroxide solution is in a concentration of 30 to 60%.

29. The process according to claim 28 wherein the stoichiometric ratio of sulphone to sodium hydroxide is 1:1.

30. The process according to any one of claims 25 to 29 wherein the oxidation is carried out at a temperature in the range of 40 to 95ºC, the tertiary oxidant and the sulphoxide/sulphone stream are agitated for a period of up to 12 minutes.

31. A process for reducing the sulphur content of a hydrocarbon material containing sulphur compounds, the process comprising:

a) contacting the hydrocarbon material with one or more primary oxidants to provide a primary oxidised hydrocarbon material such that the primary oxidant oxidizes the sulphur compounds to sulphoxide and/or sulphone compounds,

wherein the primary oxidant is selected from one or more of the group consisting of N-chloroimide, hypobromous acid, hypochlorous acid, electrolyzed oxidizing water and catalysed and co-catalysed hydrogen peroxide;

b) contacting the primary oxidised hydrocarbon material with an extractant to allow at least a portion of the sulphoxide and/or sulphone compounds to be extracted into the extractant to give a sulphoxide and/or sulphone stream and a low sulphur hydrocarbon stream; and

c) separating the sulphoxide and/or sulphone stream from the low sulphur hydrocarbon stream,

wherein the process further includes a step of contacting the sulphoxide and/or sulphone stream with a tertiary oxidant to give an aqueous sulphite stream and a low sulphur aromatic hydrocarbon stream, wherein the tertiary oxidant oxidises sulphone and/or sulphoxide compounds to sulphite compounds and wherein the tertiary oxidant consists of hydroxyl radicals such that following addition of water, sulphuric acid forms.

32. A process for reducing the sulphur content of a hydrocarbon material containing sulphur compounds, the process comprising the steps of:

a) contacting the hydrocarbon material with one or more primary oxidants to provide a primary oxidised hydrocarbon material such that the primary oxidant oxidizes the sulphur compounds to sulphoxide and/or sulphone compounds,

wherein the primary oxidant is catalysed and co-catalysed hydrogen peroxide and wherein the catalysed and co-catalysed hydrogen peroxide is hydrogen peroxide catalysed by phosphotungstic acid and co-catalysed with a phase transfer catalyst (PTC) comprising a quaternary ammonium salt, for example, a quarternary ammonium hydrogen sulphate;

b) contacting the primary oxidised hydrocarbon material with a secondary oxidant to provide a secondary oxidised hydrocarbon material,

wherein the secondary oxidant is selected from one or more of the group consisting of hydroxyl radicals and hypofluorous acid in acetonitrile prepared by bubbling a gaseous mixture comprising fluorine and nitrogen into liquid acetonitrile to form $HOF.CH_3CN$, wherein the concentration of fluorine mixed with nitrogen does not exceed 20% by weight fluorine blended with the nitrogen,

such that the secondary oxidant oxidizes sulphur compounds to sulphoxide and/or sulphone compounds;

c) contacting the primary oxidised hydrocarbon material and/or the secondary oxidised hydrocarbon material with an extractant, such as acetonitrile, to allow at least a portion of the sulphoxide and/or sulphone compounds to be extracted into the extractant to give a sulphoxide and/or sulphone stream and a low sulphur hydrocarbon stream;

d) separating the sulphoxide and/or sulphone stream from the low sulphur hydrocarbon stream; and

e) contacting the sulphoxide and/or sulphone stream with a tertiary oxidant to give an aqueous sulphite stream and a low sulphur aromatic hydrocarbon stream,

wherein the tertiary oxidant oxidises sulphone and/or sulphoxide compounds to sulphite compounds.

33. The process according to any one of claims 20 to 32 wherein oxidation with the tertiary oxidant is carried out in a range of 40 to 95ºC.

34. The process according to any one of claims 20 to 32 wherein the tertiary oxidant is hydroxyl radicals such that following addition of water, sulphuric acid forms and the stoichiometric ratio of hydroxyl radicals to sulphone/sulphoxide is in the range of 1:1 to 4:1.

35. The process according to any one of claims 1 to 34 wherein the low sulphur hydrocarbon stream and the low sulphur aromatic compound are combined and recycled as low sulphur hydrocarbon fuel.

36. The process according to claim 20 wherein the process further comprises:

e) contacting the low sulphur hydrocarbon stream obtained in step c) with an adsorbent to remove residual sulphur compounds from the low sulphur hydrocarbon stream (LSD) to provide an ultra low sulphur hydrocarbon stream (ULSD).

37. The process according to claim 36 wherein the adsorbent is selected from physical or physiochemical adsorbents, Y-zeolite, activated carbon and Metal Oxide Framework (MOF).

38. The process according to claim 36 wherein following step e) the loaded absorbent is regenerated/purged using heater N2, stripping to desorb sulfur compounds from the adsorbent.

39. The process according to any one of claims 1 to 38 wherein the low sulphur hydrocarbon stream (LSD) is polished using adsorbents including MOF (Metal Organic Framework), (C18H6Cu3O12) – Copper Benzene-1,3,5-Tricarboxylate, Metal Oxide Purification Adsorbent group of adsorbents, CuCl2MIL-47 MOF, Y-Zeolite, Molecular Imprinted Chitosan or Activated Carbon.