Claims

1. A method of desulfurizing an oil composition, the method comprising:

   flowing an oil composition comprising sulfur through a conduit comprising a constricted region, wherein oil-phase bubbles form in the constricted region and collapse by hydrodynamic cavitation in a turbulent zone downstream of the constricted region;

   contacting the oil composition with an immiscible deep eutectic solvent in the turbulent zone, thereby extracting at least a portion of the sulfur from the oil composition into association with the deep eutectic solvent; and

   separating the deep eutectic solvent and the extracted sulfur from the desulfurized oil composition.

2. The method according to claim 1, wherein contacting the oil composition with the deep eutectic solvent comprises introducing one or more streams of the deep eutectic solvent into the oil composition downstream of the constricted region, preferably by injection directly into the turbulent zone.

3. The method according to claim 2, wherein a flow of the deep eutectic solvent is directed through a flow constriction to produce solvent-phase bubbles in the one or more streams of the deep eutectic solvent introduced into the oil composition, and wherein the solvent-phase bubbles and the oil-phase bubbles collapse coincidentally in the turbulent zone to enhance extraction of the sulfur from the oil composition.

4. The method according to any one of claims 1 to 3, wherein the deep eutectic solvent comprises a eutectic mixture of a quaternary ammonium salt and a hydrogen bond donor.

5. The method according to claim 4, wherein the hydrogen bond donor is a glycol.

6. The method according to any one of claims 1 to 5, further comprising contacting the oil composition with a hydrogen donor in the turbulent zone, wherein the hydrogen donor reduces the viscosity of the desulfurized oil composition.

7. The method according to claim 6, wherein the hydrogen donor is a hydrocarbon hydrogen donor solvent.

8. The method according to any one of claims 1 to 7, further comprising contacting the oil composition with an oxidant in the turbulent zone, wherein the oxidant is added in a molar ratio of less than 0.5:1 relative to sulfur in the oil composition and wherein the oxidant oxidises sulfur-containing molecules in the oil composition to produce oxidised sulfur species and the oxidised sulfur species are at least partially extracted into the deep eutectic solvent.

9. The method according to any one of claims 1 to 8, wherein the deep eutectic solvent is a magnetic deep eutectic solvent.

10. The method according to any one of claims 1 to 9, wherein the temperature is in the range of 45 to 60°C when contacting the oil composition with the deep eutectic solvent in the turbulent zone.

11. The method according to any one of claims 1 to 10, wherein the deep eutectic solvent has a temperature dependent density, wherein the deep eutectic solvent has (i) a density which differs from the density of the desulfurized oil composition by less than 0.08 g/cm^3 when contacting the oil composition with the deep eutectic solvent in the turbulent zone, and (ii) a density which differs from the density of the desulfurized oil composition by more than 0.08 g/cm^3 when separating the deep eutectic solvent and the extracted sulfur from the desulfurized oil composition.

12. The method according to any one of claims 1 to 11, wherein flowing the oil composition through the conduit comprises circulating an inventory of the oil composition repeatedly through the conduit.

13. The method according to any one of claims 1 to 12, wherein the oil composition is a fuel oil and wherein the desulfurized oil composition has a sulfur content of no more than 1.97 wt.%.

14. A two-stage process for desulfurizing an oil composition, comprising:

in a first stage, desulfurizing an oil composition by a method according to any one of claims 1 to 13 to produce a first desulfurized oil composition; and

in a second stage, desulfurizing the first desulfurized oil composition by a method according to any one of claims 1 to 13 to produce a second desulfurized oil composition.

15. A system for desulfurizing an oil composition, the system comprising:

a conduit comprising a constricted region;

a pump for flowing an oil composition comprising sulfur through the conduit; and

one or more injection ports for introducing a stream of deep eutectic solvent to the conduit;

wherein the system is operable to:

(i) flow the oil composition through the conduit such that oil-phase bubbles form in the constricted region and collapse by hydrodynamic cavitation in a turbulent zone downstream of the constricted region; and

(ii) contact the oil composition with the deep eutectic solvent in the turbulent zone, thereby extracting at least a portion of the sulfur from the oil composition into association with the deep eutectic solvent.

16. The system according to claim 15, wherein the injection ports introduce the stream of deep eutectic solvent to the conduit downstream of the constricted region by injection directly into the turbulent zone.

17. The system according to claim 16, wherein at least one of the injection ports comprises a flow constriction configured to produce solvent-phase bubbles in the stream of deep eutectic solvent introduced into the conduit.

18. The system according to any one of claims 15 to 17, further comprising a separator for separating the deep eutectic solvent and the extracted sulfur from the desulfurized oil composition.

19. The system according to claim 18, wherein the separator is selected from a magnetic separator and a triphase liquid-liquid separator for separating a phase

rich in desulfurized oil composition, a phase rich in deep eutectic solvent, and a phase rich in sulfur-containing compounds.

20. The system according to any one of claims 15 to 19, further comprising a reservoir for holding an inventory of the oil composition to be flowed, by the pump, through the conduit, wherein the system is configured to circulate the inventory of the oil composition repeatedly through the conduit.