Claims

1. A method for producing fuel oil, it is characterized in that the method comprises the following steps:

(1) bringing a sulfur-containing feedstock oil and an alkali metal into contact for a pre-reaction to obtain a pre-reaction material, wherein the pre-reaction is performed under hydrogen-free conditions;

(2) contacting the pre-reaction material with a hydrogen-supplying agent to perform a hydrogenation reaction;

(3) separating the material obtained in step (2) to obtain a liquid-phase product fuel oil and a solid mixture;

wherein the hydrogen-free conditions in step (1) refer to that the hydrogen-supplying agent is not added in the pre-reaction process, and the pre-reaction temperature in step (1) is within a range of 200°C-400°C.

2. The method according to claim 1, wherein

the pre-reaction temperature in step (1) is within a range of 300°C-380°C; and/or

the alkali metal in step (1) is provided in the form of a molten alkali metal; and/or

the alkali metal in step (1) is one or more selected from the group consisting of lithium, sodium, potassium, rubidium, cesium and francium; and/or

a mass ratio of the alkali metal in step (1) relative to sulfur in the sulfur-containing feedstock oil is 0.8-3.0:1, preferably 1-2.5:1, more preferably 1.1-1.4:1; and/or

the sulfur content in the sulfur-containing feedstock oil is 1.0 wt% or more, preferably 1.8-8.0 wt%, more preferably 2-3 wt%;

it is preferable that the sulfur-containing feedstock oil has a density within a range of 950-1,000 kg/m^3, and/or a heavy metal content within a range of 110-200 wppm, and/or a carbon residue content within a range of 5-15 wt%, and/or a viscosity within a range of 800-20,000 cSt.

3. The method according to claim 1 or 2, wherein

the contact in step (1) is performed in a mixer;

preferably, the mixer is one or more selected from the group consisting of a pipeline mixer, a liquid-liquid stirring mixer, a whirlpool mixer and a static mixer;

preferably, the mixer comprises a closed feed hopper, a mixer body, a drive shaft assembly, a pulley mechanism and an electric motor; the mixer body comprises a stationary millstone fixed inside the mixer body and a movable millstone for cooperating with the stationary millstone; the movable millstone is connected with the drive shaft assembly, the pulley mechanism and the electric motor to provide a power source; the stationary millstone and the movable millstone are set to be

corresponding in an one-by-one manner to form a group, preferably 1-7 groups, more preferably 2-4 groups are set sequentially in a longitudinal direction of the drive shaft assembly;

more preferably, the mixing process in the mixer comprises: the sulfur-containing feedstock oil and the alkali metal source in the molten state enter a closed feed hopper from the top of said mixer, then access the mixer body, the stationary millstones are fixed on the mixer body and in a relatively static state; the electric motor provides power, and perform power transmission via the pulley mechanism, so that the drive shaft assembly starts to operate, in the meanwhile, the movable millstones drive the corresponding stationary millstones to rotate, such that the reactants are sufficiently blended during the flow process from the top to the bottom.

4. The method according to any of claims 1-3, wherein

the hydrogen-supplying agent in step (2) is a substance containing at least one hydrogen atom, preferably hydrogen gas and/or a substance containing at least one carbon atom and at least one hydrogen atom;

preferably, the hydrogen-supplying agent is hydrogen gas and/or C1-C5 lower carbon hydrocarbons; more preferably, the lower carbon hydrocarbon is one or more selected from the group consisting of methane, ethane, propane, butane, pentane, ethylene, propylene, butylene,

pentene and diene, preferably the hydrogen-supplying agent is hydrogen gas and/or ethane; and/or

the used amount of hydrogen-supplying agent in step (2) is within a range of 1.0-3.0 mole hydrogen/mole sulfur, preferably within a range of 1.5-2.5 mole hydrogen/mole sulfur, calculated based on hydrogen gas; and/or

the conditions of the hydrogenation reaction in step (2) comprise:

an operating pressure within a range of 4.0-10.0 Mpa, preferably 6.0-8.0 Mpa; and/or

a reaction temperature within a range of 200°C-430°C, preferably 300°C-380°C, more preferably 365°C-380°C.

5. The method according to any of claims 1-4, wherein

the step (2) is performed in a reactor, which is one or more selected from the group consisting of a suspended bed reactor, an ebullated bed reactor, a fixed bed reactor, and a CSTR reactor;

preferably, the reactor is a suspended bed reactor, the operating conditions comprise: a reaction pressure within a range of 4.0-10.0 MPa, preferably 6.0-8.0 MPa; a reaction temperature within a range of 200-430°C, preferably 300-380°C, more preferably 365-380°C; and/or

the step (2) is performed in the presence of a catalyst, an active metal element of the catalyst comprise one or more of molybdenum, nickel and

cobalt, the catalyst is preferably one or more selected from the group consisting of metallic molybdenum, metallic nickel, metallic cobalt, molybdenum alloy, nickel alloy, cobalt alloy, molybdenum oxide, nickel oxide and cobalt oxide; the molybdenum alloy is preferably a molybdenum alloy containing nickel and/or cobalt, the nickel alloy is preferably a nickel alloy containing cobalt and/or molybdenum.

6. The method according to any of claims 1-5, wherein the separating in step (3) is performed using one or more of cyclone separation, centrifuge separation, extraction separation, filtration separation and sedimentation separation; preferably cyclone separation; more preferably, the operating temperature of the cyclone separation is within a range of 150°C-380°C, preferably 200°C-330°C, more preferably 280°C-290°C.

7. The method according to any one of claims 1-6, wherein the method comprises: before the separating in step (3) is carried out, subjecting the material obtained in step (2) to a stabilization treatment under the hydrogenation reaction conditions for a stabilization period of 1-6h, preferably 2-3h.

8. The method according to any one of claims 1-7, wherein the method further comprises: a step (4) of mixing the solid mixture obtained in step

(3) with a polar solvent capable of dissolving an alkali metal sulfide, the alkali metal sulfide in the solid mixture is dissolved in the polar solvent;

preferably, the polar solvent in step (4) is one or more selected from the group consisting of N,N-dimethylaniline, quinoline, 2-methyltetrahydrofuran, benzene, tetrahydrofuran, cyclohexane, fluorobenzene, trifluorobenzene, toluene, xylene, tetraethyleneglycol dimethyl ether, diglyme, isopropanol, ethylpropionaldehyde, dimethyl carbonate, dimethoxy ether, dimethyl propyleneurea, ethanol, ethyl acetate, propylene carbonate, ethylene carbonate and diethyl carbonate.

9. The method according to claim 8, wherein the method further comprises: a step (5) of introducing the alkali metal sulfide-containing polar solvent obtained in said step (4) into an electrolysis unit, electrolyzing the alkali metal sulfide to produce an alkali metal and sulfur, and recycling the alkali metal as a raw material.

10. The method according to any of claims 1-9, wherein the method comprises the following steps:

(1) carrying out the pre-reaction of the sulfur-containing feedstock oil with an alkali metal in a mixer to obtain a pre-reaction material, the pre-reaction is performed under hydrogen-free conditions, the pre-reaction temperature is within a range of 200°C-400°C, preferably

within a range of 300°C-380°C;

(2) contacting the pre-reaction material with a hydrogen-supplying agent to perform a hydrogenation reaction;

(3) separating the material obtained in step (2) to obtain a liquid-phase product fuel oil and a solid mixture;

(4) mixing the solid mixture obtained in step (3) with a polar solvent capable of dissolving an alkali metal sulfide, the alkali metal sulfide is dissolved in the polar solvent;

(5) introducing the alkali metal sulfide-containing polar solvent obtained in step (4) into an electrolysis unit, electrolyzing the alkali metal sulfide to generate an alkali metal and sulfur, and recycling the alkali metal as a raw material.

11. An application of the method of any one of claims 1-10 in the production of low-sulfur marine fuel oil.

12. A system for producing a fuel oil, it is characterized in that the system comprises:

(1) a pre-reaction unit for bringing a sulfur-containing feedstock oil and an alkali metal into contact for a pre-reaction to obtain a pre-reaction material;

(2) a hydrogenation reaction unit for contacting the pre-reaction material

with a hydrogen-supplying agent to perform a hydrogenation reaction;

(3) a separation unit for separating the hydrogenation reaction material;

wherein the system further comprises:

a dissolution unit for mixing the solid mixture obtained from the separation unit with a polar solvent capable of dissolving an alkali metal sulfide, so that the alkali metal sulfide is dissolved in the polar solvent;

an electrolysis unit for electrolyzing the alkali metal sulfide in an alkali metal sulfide-containing polar solvent obtained in the dissolution unit to generate an alkali metal and sulfur.

13. The system according to claim 12, wherein

the pre-reaction unit comprises a mixer, preferably one or more selected from the group consisting of a pipeline mixer, a liquid-liquid stirring mixer, a whirlpool mixer and a static mixer;

more preferably, the mixer comprises a closed feed hopper, a mixer body, a drive shaft assembly, a pulley mechanism and an electric motor; the mixer body comprises a stationary millstone fixed inside the mixer body and a movable millstone for cooperating with the stationary millstone; the movable millstone is connected with the drive shaft assembly, the pulley mechanism and the electric motor to provide a power source; the stationary millstone and the movable millstone are set to be corresponding in an one-by-one manner to form a group, preferably 1-7

groups, more preferably 2-4 groups are set sequentially in a longitudinal direction of the drive shaft assembly; and/or

the reaction unit comprises: one or more selected from the group consisting of a suspended bed reactor, an ebullated bed reactor, a fixed bed reactor and a CSTR reactor, preferably a suspended bed reactor; and/or

the separation unit comprises one or more selected from the group consisting of a cyclone separator, a centrifuge separator, an extraction separator, a filtration separator and a sedimentation separator, preferably a cyclone separator.

14. The system according to claim 12, wherein the individual unit is provided with a plurality of feed lines and discharge lines as required; more preferably, the system comprises: a sulfur-containing feedstock oil feed line, an alkali metal feed line, a mixer discharge line, a reactor outlet line for generated oil, a liquid product line, a solid mixture discharge line, a polar solvent feed line, a dissolution tank, a dissolved mixture discharge line, a metal or other solid component discharge line, an alkali metal sulfide-containing polar solvent discharge line, a sulfur discharge line and a recycled alkali metal feed line.