Claims

1. A method for the desulfurization and separation of a catalytic cracking light product, comprising the steps of:

1) contacting a catalytic cracking light product with a desulfurization adsorbent in an adsorption desulfurization reaction unit in the presence of hydrogen for desulfurization, and carrying out gas-liquid separation on the resulting desulfurization product, to obtain a desulfurized rich gas and a desulfurized crude gasoline, wherein the catalytic cracking light product is an overhead oil-gas fraction from a catalytic cracking fractionator,

or,

contacting a catalytic cracking light product with a desulfurization adsorbent in an adsorption desulfurization reaction unit in the presence of hydrogen for desulfurization, to obtain a desulfurized rich gas and a desulfurized crude gasoline, wherein the catalytic cracking light product is a rich gas and a crude gasoline from a catalytic cracking fractionator; and

2) separately sending the desulfurized rich gas and the desulfurized crude gasoline obtained in the step 1) to a catalytic cracking absorption stabilization system for separation, to obtain a desulfurized dry gas, a desulfurized liquefied gas and a desulfurized stabilized gasoline.

2. The method according to claim 1, wherein the catalytic cracking absorption stabilization system comprises an absorber, a reabsorber, a desorber, and a stabilizer, and the step 2) further comprises:

2a) introducing the desulfurized rich gas into an absorber from the bottom, and contacting it with the desulfurized crude gasoline introduced into the absorber from the top in a countercurrent manner for mass transfer, to obtain an overhead stream and a bottom product;

2b) introducing the overhead stream of the absorber into a reabsorber from the bottom, and contacting it with a light cycle oil from the catalytic cracking fractionator introduced into the reabsorber from the top in a countercurrent manner for mass transfer, to obtain the

desulfurized dry gas at the top of the reabsorber and an enriched light cycle oil at the bottom of the reabsorber, and optionally recycling the enriched light cycle oil to the catalytic cracking fractionator;

2c) desorbing the bottom product of the absorber in the desorber to obtain an overhead gas and a bottom product, and optionally recycling the overhead gas to the absorber; and

2d) sending the bottom product of the desorber to the stabilizer, and fractionating it in the stabilizer to obtain the desulfurized liquefied gas and the desulfurized stabilized gasoline;

the operating conditions of the absorber preferably include: a pressure of 0.2-3.0MPa, preferably 0.5-1.6MPa, a temperature of 20-100 °C, preferably 30-70 °C;

the operating conditions of the desorber preferably include: a pressure of 0.1-3.0MPa, preferably 0.5-2.5MPa, a temperature of 20-250 °C, preferably 50-200 °C;

the operating conditions of the reabsorber preferably include: a pressure of 0.1-3.0MPa, preferably 0.5-2.5MPa, a temperature of 20-100 °C, preferably 30-70 °C; and

the operating conditions of the stabilizer preferably include: a pressure of 0.1-3.0MPa, preferably 0.5-2.5MPa, and a temperature of 20-250 °C, preferably 50-200 °C.

3. The method according to claim 1 or 2, wherein the catalytic cracking light product is an overhead oil-gas fraction from a catalytic cracking fractionator, and the step 1) further comprises:

1a) introducing the overhead oil-gas fraction from the catalytic cracking fractionator into a fluidized bed desulfurization reactor from the bottom, and contacting it with a desulfurization adsorbent introduced into the reactor from the bottom in the presence of hydrogen for desulfurization reaction;

1b) carrying out gas-solid separation on the reaction stream obtained at the upper part of the fluidized bed desulfurization reactor to obtain a reaction oil gas and a sulfur-loaded adsorbent;

1c) carrying out gas-liquid separation on the reaction oil gas obtained in the step 1b) to obtain the desulfurized rich gas and the desulfurized crude gasoline, wherein preferably, the operating conditions of the gas-liquid separation include: a pressure of 0.2-4.0MPa, preferably 0.5-3.0MPa, and a temperature of 20-300 °C, preferably 50-200 °C; and

1d) sending the sulfur-loaded adsorbent obtained in the step 1b) to an adsorbent regenerator for regeneration by calcining in the presence of an oxygen-containing gas, and recycling the regenerated desulfurization adsorbent to the fluidized bed desulfurization reactor after reduction,

preferably, the overhead oil-gas fraction of the catalytic cracking fractionator comprises C1-C12 hydrocarbon components, and has a sulfur content of 30-50000 μg/g.

4. The method according to claim 1 or 2, wherein the catalytic cracking light product is a rich gas and a crude gasoline from a catalytic cracking fractionator, and the step 1) further comprises:

1a) introducing the crude gasoline from the catalytic cracking fractionator into a fluidized bed desulfurization reactor from the bottom, and contacting it with a desulfurization adsorbent introduced into the reactor from the bottom in the presence of hydrogen for desulfurization reaction;

1b) introducing the rich gas from the catalytic cracking fractionator into the fluidized bed desulfurization reactor at a position of 30-80%, preferably 40-70%, of the height thereof from bottom to top, and mixing it with the stream in the reactor for desulfurization reaction;

1c) carrying out gas-solid separation on the reaction stream obtained at the upper part of the fluidized bed desulfurization reactor to obtain a reaction oil gas and a sulfur-loaded adsorbent;

1d) carrying out gas-liquid separation on the reaction oil gas obtained in the step 1c) to obtain the desulfurized rich gas and the desulfurized crude gasoline, wherein preferably, the operating conditions of the gas-liquid separation include: a pressure of 0.2-4.0MPa, preferably 0.5-3.0MPa, and a temperature of 20-300 °C, preferably 50-200 °C; and

1e) sending the sulfur-loaded adsorbent obtained in the step 1c) to an adsorbent regenerator for regeneration by calcining in the presence of an oxygen-containing gas, and recycling the regenerated desulfurization adsorbent to the fluidized bed desulfurization reactor after reduction,

preferably, the sulfur content in the rich gas and in the crude gasoline from the catalytic cracking fractionator are each independently greater than 30 μg/g, particularly greater than

50 μg/g.

5. The method according to claim 3 or 4, wherein the operating conditions of the fluidized bed desulfurization reactor include:

a temperature of 200-550 °C, preferably 300-500 °C; an absolute pressure of 0.5-5 MPa, preferably 1.0-3.5 MPa: a weight hourly space velocity of oil gas feedstock of 0.1-100 h^{-1}, preferably 1-10 h^{-1}; and a hydrogen-to-oil molar ratio of 0.01-5, preferably 0.1-1.

6. The method according to claim 1 or 2, wherein the catalytic cracking light product is a rich gas and a crude gasoline from a catalytic cracking fractionator, and the step 1) further comprises:

1a) introducing the crude gasoline from the catalytic cracking fractionator into a first fluidized bed desulfurization reactor from the bottom, and contacting it with a desulfurization adsorbent introduced into the reactor from the bottom in the presence of hydrogen for desulfurization reaction;

1b) carrying out gas-solid separation on the reaction stream obtained at the upper part of the first fluidized bed desulfurization reactor to obtain the desulfurized crude gasoline and a desulfurization adsorbent partially loaded with sulfur, and sending the desulfurization adsorbent partially loaded with sulfur into a second fluidized bed desulfurization reactor;

1c) introducing the rich gas from the catalytic cracking fractionator into the second fluidized bed desulfurization reactor from the bottom, and contacting it with the desulfurization adsorbent partially loaded with sulfur introduced into the reactor from the bottom for desulfurization reaction;

1d) carrying out gas-solid separation on the reaction stream obtained at the upper part of the second fluidized bed desulfurization reactor to obtain the desulfurized rich gas and a sulfur-loaded adsorbent; and

1e) sending the sulfur-loaded adsorbent obtained in the step 1d) to an adsorbent regenerator for regeneration by calcining in the presence of an oxygen-containing gas, and recycling the regenerated desulfurization adsorbent to the first fluidized bed desulfurization reactor after reduction.

7. The method according to claim 6, wherein:

the operating conditions of the first fluidized bed desulfurization reactor include: a temperature of 200-550 °C, preferably 300-500 °C; an absolute pressure of 0.5-5 MPa, preferably 1.0-3.5 MPa; a weight hourly space velocity of oil gas feedstock of 0.1-100 h^{-1}, preferably 1-10 h^{-1}; and a hydrogen-to-oil molar ratio of 0.01-1000, preferably 0.05-500;

the operating conditions of the second fluidized bed desulfurization reactor include: a temperature of 300-550 °C, preferably 350-500 °C; an absolute pressure of 0.1-3 MPa, preferably 0.2-2.5 MPa; a weight hourly space velocity of oil gas feedstock of 1-100 h^{-1}, preferably 2-20 h^{-1}; and a hydrogen-to-oil molar ratio of 0.01-500, preferably 0.05-300; and

the operating temperature of the second fluidized bed desulfurization reactor is 0.5-2.0 MPa lower than that of the first fluidized bed desulfurization reactor.

8. The method according to claim 1 or 2, wherein the catalytic cracking light product is a rich gas and a crude gasoline from a catalytic cracking fractionator, and the step 1) further comprises:

1a) introducing the crude gasoline from the catalytic cracking fractionator into a first fluidized bed desulfurization reactor from the bottom, and contacting it with a desulfurization adsorbent introduced into the reactor from the bottom in the presence of hydrogen for desulfurization reaction;

1b) carrying out gas-solid separation on the reaction stream obtained at the upper part of the first fluidized bed desulfurization reactor to obtain a first reaction oil gas and a desulfurization adsorbent partially loaded with sulfur, and sending the desulfurization adsorbent partially loaded with sulfur into a second fluidized bed desulfurization reactor;

1c) introducing the rich gas from the catalytic cracking fractionator into the second fluidized bed desulfurization reactor from the bottom, and contacting it with the desulfurization adsorbent partially loaded with sulfur introduced into the reactor from the bottom for desulfurization reaction;

1d) carrying out gas-solid separation on the reaction stream obtained at the upper part of the second fluidized bed desulfurization reactor to obtain a second reaction oil gas and a sulfur-loaded adsorbent, and recycling the second reaction oil gas to the first fluidized bed desulfurization reactor;

1e) carrying out gas-liquid separation on the first reaction oil gas obtained in the step 1b) to obtain the desulfurized rich gas and the desulfurized crude gasoline; and

1f) sending the sulfur-loaded adsorbent obtained in the step 1d) to an adsorbent regenerator for regeneration by calcining in the presence of an oxygen-containing gas, and recycling the regenerated desulfurization adsorbent to the fluidized bed desulfurization reactor after reduction.

9. The method according to claim 8, wherein:

the operating conditions of the first fluidized bed desulfurization reactor include: a temperature of 200-550 °C, preferably 300-500 °C, an absolute pressure of 0.5-5 MPa, preferably 1.0-3.5 MPa, a weight hourly space velocity of oil gas feedstock of 0.1-100 h^{-1}, preferably 1-10 h^{-1}, and a hydrogen-to-oil molar ratio of 0.01-1000, preferably 0.05-500; and

the operating conditions of the second fluidized bed desulfurization reactor include: a temperature of 300-550 °C, preferably 350-500 °C, an absolute pressure of 0.5-5 MPa, preferably 1.0-3.5 MPa, a weight hourly space velocity of oil gas feedstock of 1-100 h^{-1}, preferably 2-20 h^{-1}, and a hydrogen-to-oil molar ratio of 0.01-500, preferably 0.05-300.

10. The method according to claim 1 or 2, wherein the catalytic cracking light product is a rich gas and a crude gasoline from a catalytic cracking fractionator, and the step 1) further comprises:

1a) introducing the crude gasoline from the catalytic cracking fractionator into a first fluidized bed desulfurization reactor from the bottom, and contacting it with a desulfurization adsorbent introduced into the reactor from the bottom in the presence of hydrogen for desulfurization reaction;

1b) withdrawing a part of the desulfurization adsorbent from the middle-lower part of the first fluidized bed desulfurization reactor and passing it to the bottom of a second fluidized bed desulfurization reactor, contacting it with the rich gas from the catalytic cracking fractionator introduced into the reactor from the bottom for desulfurization reaction, and recycling the reaction stream obtained from the upper part of the second fluidized bed desulfurization reactor;

1c) carrying out gas-solid separation on the reaction stream obtained at the upper part

of the first fluidized bed desulfurization reactor to obtain a reaction oil gas and a sulfur-loaded adsorbent;

1d) carrying out gas-liquid separation on the reaction oil gas obtained in the step 1c) to obtain the desulfurized rich gas and the desulfurized crude gasoline; and

1e) sending the sulfur-loaded adsorbent obtained in the step 1c) to an adsorbent regenerator for regeneration by calcining in the presence of an oxygen-containing gas, and recycling the regenerated desulfurization adsorbent to the first fluidized bed desulfurization reactor after reduction.

11. The method according to claim 10, wherein:

the operating conditions of the first fluidized bed desulfurization reactor include: a temperature of 200-550 °C, preferably 300-500 °C, an absolute pressure of 0.5-5 MPa, preferably 1.0-3.5 MPa, a weight hourly space velocity of oil gas feedstock of 0.1-100 h^{-1}, preferably 1-10 h^{-1}, and a hydrogen-to-oil molar ratio of 0.01-1000, preferably 0.05-500;

the operating conditions of the second fluidized bed desulfurization reactor include: a temperature of 250-550 °C, preferably 350-500 °C, an absolute pressure of 0.5-5 MPa, preferably 1.0-3.5 MPa, a weight hourly space velocity of oil gas feedstock of 0.1-100 h^{-1}, preferably 1-20 h^{-1}, and a hydrogen-to-oil molar ratio of 0.01-1000, preferably 0.05-300.

12. The method according to claim 1 or 2, wherein the catalytic cracking light product is a rich gas and a crude gasoline from a catalytic cracking fractionator, and the step 1) further comprises:

1a) introducing the crude gasoline from the catalytic cracking fractionator into a first fluidized bed desulfurization reactor from the bottom, and contacting it with a desulfurization adsorbent introduced into the reactor from the bottom in the presence of hydrogen for desulfurization reaction;

1b) carrying out gas-solid separation on the reaction stream obtained at the upper part of the first fluidized bed desulfurization reactor to obtain the desulfurized crude gasoline and a sulfur-loaded adsorbent, and sending a part of the resulting sulfur-loaded adsorbent to the upper part of a second fluidized bed desulfurization reactor;

1c) introducing the rich gas from the catalytic cracking fractionator into the second

fluidized bed desulfurization reactor from the bottom, contacting it with the sulfur-loaded adsorbent introduced into the reactor from the upper part thereof in a countercurrent manner for desulfurization reaction, to obtain the desulfurized rich gas at the top of the second fluidized bed desulfurization reactor, and withdrawing the reacted sulfur-loaded adsorbent from the bottom of the second fluidized bed desulfurization reactor and recycling it to the first fluidized bed desulfurization reactor; and

1e) sending the rest of the sulfur-loaded adsorbent obtained in the step 1b) to an adsorbent regenerator for regeneration by calcining in the presence of an oxygen-containing gas, and recycling the regenerated desulfurization adsorbent to the first fluidized bed desulfurization reactor after reduction.

13. The method according to claim 12, wherein the feed gas velocity of the first fluidized bed desulfurization reactor is 0.25-10 m/s and the feed gas velocity of the second fluidized bed desulfurization reactor is 0.05-1.5 m/s.

14. The method according to claim 12 or 13, wherein:

the operating conditions of the first fluidized bed desulfurization reactor include: a temperature of 200-550 °C, preferably 300-500 °C, an absolute pressure of 0.5-5 MPa, preferably 1.0-3.5 MPa, a weight hourly space velocity of oil gas feedstock of 0.1-100 h^{-1}, preferably 1-10 h^{-1}, and a hydrogen-to-oil molar ratio of 0.01-1000, preferably 0.05-500;

the operating conditions of the second fluidized bed desulfurization reactor include: a temperature of 300-550 °C, preferably 350-500 °C, an absolute pressure of 0.5-5 MPa, preferably 1.0-3.5 MPa, a weight hourly space velocity of oil gas feedstock of 0.1-100 h^{-1}, preferably 1-20 h^{-1}, and a hydrogen-to-oil molar ratio of 0.01-500, preferably 0.05-300.

15. The method according to any one of claims 3 to 14, wherein the operating conditions of the adsorbent regenerator include:

a regeneration temperature of 300-800 °C, preferably 350-600 °C, and a regeneration pressure of 0.1-3.0MPa, preferably 0.1-1.0 MPa.

16. A method according to any one of the preceding claims, wherein the desulfurization adsorbent comprises an desulfurization adsorbent carrier and a metal component loaded on the adsorbent carrier, the content of the desulfurization adsorbent carrier is 70-95 wt%, the

content of the metal component is 5-30 wt%, based on the total weight of the desulfurization adsorbent, the adsorbent carrier is selected from zinc oxide, silica, alumina or a mixture thereof, and the metal component is selected from cobalt, nickel, copper, iron, manganese, molybdenum, tungsten, silver, tin, vanadium, or a combination thereof.

17. A process for producing a low-sulfur light oil product by catalytic cracking, comprising the steps of:

i) contacting a catalytic cracking feedstock with a catalytic cracking catalyst for reaction under catalytic cracking conditions, preferably in a riser reactor;

ii) carrying out gas-solid separation on the reaction product obtained in the step i) to obtain a reaction oil gas and a spent catalyst;

iii) fractionating the reaction oil gas obtained in the step ii) in a catalytic cracking fractionator to obtain a catalytic cracking light product, a light cycle oil, a diesel oil and an oil slurry;

iv) desulfurizing and separating the catalytic cracking light product from the catalytic cracking fractionator using the method according to any one of claims 1 to 16 to obtain a desulfurized dry gas, a desulfurized liquefied gas and a desulfurized stabilized gasoline; and

v) optionally, regenerating the spent catalyst obtained in the step ii) and then recycling the regenerated catalyst to the riser reactor for reuse.

18. An apparatus for the desulfurization and separation of a catalytic cracking light product, comprising an adsorption desulfurization unit and an absorption stabilization unit communicated in sequence;

the absorption stabilization unit comprises an absorber, a desorber, a reabsorber and a stabilizer communicated in sequence; and

the adsorption desulfurization unit comprises a fluidized bed desulfurization reaction unit, an adsorbent regenerator and a lock hopper connected between them that is used for conducting pressure changing and atmosphere conversion, the fluidized bed desulfurization reaction unit is in communication with a catalytic cracking fractionator to receive a catalytic cracking light product from the catalytic cracking fractionator, and an oil-gas outlet of the fluidized bed desulfurization reaction unit is in communication with the absorber of the

absorption stabilization unit or communicated with the absorber of the absorption stabilization unit through a gas-liquid separation tank.

19. The apparatus according to claim 18, wherein the adsorption desulfurization unit comprises: a fluidized bed desulfurization reaction unit, a reactor receiver, a lock hopper, a regenerator feed tank, an adsorbent regenerator and a regenerator receiver communicated in sequence, the regenerator receiver is communicated with an adsorbent reductor through the lock hopper, and the adsorbent reductor is in communication with the fluidized bed desulfurization reaction unit.

20. The apparatus according to claim 19, wherein the fluidized bed desulfurization reaction unit comprises a first fluidized bed desulfurization reactor, an optional adsorbent transferring tank, and a second fluidized bed desulfurization reactor communicated in sequence, and the adsorbent reducer is in communication with the bottom of the first fluidized bed desulfurization reactor and/or the second fluidized bed desulfurization reactor.

21. The apparatus according to claim 19, wherein the fluidized bed desulfurization reaction unit comprises a first fluidized bed desulfurization reactor and a second fluidized bed desulfurization reactor, wherein the first fluidized bed desulfurization reactor is in communication with the reactor receiver, the adsorbent reducer is in communication with the bottom of the first fluidized bed desulfurization reactor and/or the second fluidized bed desulfurization reactor, the middle-lower part of the first fluidized bed desulfurization reactor is in communication with the bottom of the second fluidized bed desulfurization reactor, and the upper part of the second fluidized bed desulfurization reactor is in communication with the upper part of the first fluidized bed desulfurization reactor;

preferably, the first fluidized bed desulfurization reactor is communicated at a position of 20-60% of the height thereof from bottom to top with the bottom of the second fluidized bed desulfurization reactor, the first fluidized bed desulfurization reactor is communicated at a position of 60-90% of the height thereof from bottom to top with the upper part of the second fluidized bed desulfurization reactor, a gas-solid separation equipment is provided in a settling section at the upper part of the first fluidized bed desulfurization reactor, and a gas-solid separation equipment is provided or not provided at the upper part of the second

fluidized bed desulfurization reactor.

22. The apparatus according to claim 19, wherein the fluidized bed desulfurization reaction unit comprises a first fluidized bed desulfurization reactor and a second fluidized bed desulfurization reactor, wherein the first fluidized bed desulfurization reactor is in communication with the reactor receiver, the adsorbent reducer is in communication with the bottom of the first fluidized bed desulfurization reactor and/or the second fluidized bed desulfurization reactor, the upper part of the first fluidized bed desulfurization reactor is in communication with the upper part of the second fluidized bed desulfurization reactor, and the bottom of the second fluidized bed desulfurization reactor is in communication with the bottom of the first fluidized bed desulfurization reactor;

preferably, the first fluidized bed desulfurization reactor is communicated at a position of 50-90% of the height thereof from bottom to top with the second fluidized bed desulfurization reactor at a position of 80-90% of the height thereof from bottom to top.