

Wax Oil Hydrogenation Method and System

Field of the Invention

The present invention relates to the petroleum refining field, particularly to wax oil hydrogenation method and system.

Background of the Invention

Fluidized catalytic cracking (FCC) is one of the most important means for heavy oil lightening. However, as the FCC feedstock is deteriorated and heavier, the operating conditions become more and more harsh, and the yield and properties of light products are poorer. Hydro-treating techniques for FCC feedstock not only can remove impurities such as sulfur, nitrogen, metal, etc., but also can improve the cracking performance of the feedstock, mitigate FCC operation severity, improve product distribution, improve the selectivity for target product, reduce the yield of dry gas and coke, improve the economic efficiency of FCC unit, reduce the sulfur content in target product, and reduce the SO_x and NO_x content in regenerated flue gas, etc. Light catalytic cracking cycle oil (LCO) has certain content of sulfur and nitrogen that exist in the form of organic compounds, and has high content of aromatic hydrocarbons, especially bicyclic and polycyclic aromatic hydrocarbons. The LCO is usually directly recycled to the FCC unit for further conversion or is hydrogenated in a hydro-treating unit and then returned to the FCC unit, or is processed in other apparatuses, or is directly taken as a product.

The patent documents CN103773495A, CN101875856A, CN102465035A and CN1896192A have disclosed a technique for blending light catalytic cracking cycle oil in a wax oil hydro-treating process mainly for producing high-quality FCC feedstock or a coupling technique for circulation of light catalytic cracking cycle oil between a wax oil hydro-treating unit and a FCC unit to realize clean production of the FCC unit. However, since the wax oil is directly hydrogenated after it is mixed with light catalytic cracking cycle oil, the hydrogenation depth of the light catalytic cracking cycle oil can't be effectively controlled; instead, the sulfur content or nitrogen content in the mixed hydrogenation product (FCC feedstock) has to be used as the control indicators for the control. That approach is not favorable for effective control of production of high-quality gasoline with light catalytic cracking cycle oil.

In summary, with existing light catalytic cracking cycle oil hydrogenation techniques and wax oil hydrogenation techniques, usually the light catalytic cracking cycle oil is directly blended into the wax oil hydro-treating unit for hydrogenation, and the hydrogenated wax oil and hydrogenated light

catalytic cracking cycle oil obtained after mixing and hydrogenation are used as the feedstock for a catalytic cracking unit, i.e., the light catalytic cracking cycle oil is returned to the FCC unit after it is hydrogenated. Since the hydrogenation depth of the light catalytic cracking cycle oil is not controlled rigorously, the quality of the obtained catalytic cracking gasoline is not the best; moreover, there is
5 no combined processing technique for coupled reaction materials.

Summary of the Invention

To overcome the above-mentioned drawbacks in the prior art, the present invention provides wax oil hydrogenation method and system. In the present invention, wax oil and light catalytic cracking
10 cycle oil are treated through a combined process of hydro-treating and hydrofining to produce high-quality FCC feedstock; in addition, the process is flexible, and the energy consumption is low.

To attain the object described above, in a first aspect, the present invention provides a wax oil hydrogenation method, which comprises the following steps:

(1) controlling wax oil as feedstock and a hydrogen-containing gas to contact with a first
15 hydro-treating catalyst under first hydro-treating conditions, dividing a first hydro-treated stream obtained through the contact into two parts, i.e., a first hydro-treated stream **A** and a first hydro-treated stream **B**, and performing gas-liquid separation of the first hydro-treated stream **A** to obtain a first hydro-treated gas-phase stream and a first hydro-treated liquid-phase stream;

(2) controlling the first hydro-treated stream **B**, the first hydro-treated liquid-phase stream, and a
20 hydrogen-containing gas to contact with a second hydro-treating catalyst under second hydro-treating conditions, to obtain a resultant hydro-treated stream; and

(3) controlling the first hydro-treated gas-phase stream and light catalytic cracking cycle oil to contact with a hydrofining catalyst to have a hydrofining reaction under hydrofining conditions, to obtain a resultant hydro-fined stream.

Preferably, the method further comprises cutting the light catalytic cracking cycle oil to obtain a light
25 fraction and a heavy fraction, wherein the cutting temperature is 245-300°C; the step (3) comprises: controlling the first hydro-treated gas-phase stream, the heavy fraction, and a hydrogen-containing gas to contact with a first hydrofining catalyst to have a first hydrofining reaction under first hydrofining conditions, to obtain a first hydro-fined stream; then controlling the first hydro-fined
30 stream, the light fraction, and a hydrogen-containing gas to contact with a second hydrofining catalyst to have a second hydrofining reaction under second hydrofining conditions. Further preferably, the temperature of the second hydrofining reaction is lower than the temperature of the

first hydrofining reaction; still further preferably, the temperature of the second hydrofining reaction is lower than the temperature of the first hydrofining reaction by 5-20°C (more preferably 10-20°C). With the preferred embodiment, the depth of aromatic hydrogenation can be controlled better to obtain more monocyclic aromatic hydrocarbons under a premise of meeting the requirement for sulfur content.

In a second aspect, the present invention provides a wax oil hydrogenation system, which comprises:

a first hydro-treating unit;

a gas-liquid separator configured to perform gas-liquid separation for a part of first hydro-treated stream obtained in the first hydro-treating unit to obtain a first hydro-treated gas-phase stream and a first hydro-treated liquid-phase stream;

a second hydro-treating unit configured to perform second hydro-treatment for the remaining part of the first hydro-treated stream and the first hydro-treated liquid-phase stream in it to obtain a resultant hydro-treated stream;

a light catalytic cracking cycle oil supply unit configured to supply light catalytic cracking cycle oil; and

a hydrofining unit configured to perform hydrofining for the light catalytic cracking cycle oil supplied by the light catalytic cracking cycle oil supply unit and the hydro-treated gas-phase stream in it to obtain a resultant hydro-fined stream.

Preferably, the hydrofining unit comprises a first hydrofining unit and a second hydrofining unit that are arranged in series; the system further comprises: a light catalytic cracking cycle oil fractionation tower arranged between the first hydrofining unit and the light catalytic cracking cycle oil supply unit to cut the light catalytic cracking cycle oil supplied by the light catalytic cracking cycle oil supply unit into a light fraction and a heavy fraction; the heavy fraction and the first hydro-treated gas-phase stream are hydro-fined in the first hydrofining unit to obtain a first hydro-fined stream; the first hydro-fined stream and the light fraction are hydro-fined in the second hydrofining unit to obtain the resultant hydro-fined stream.

The requirements for product quality, environmental protection and process operation, etc. set constraints on the properties of the feedstock for a FCC unit, especially the the limitation of sulfur content. Moreover, the distribution and properties of FCC products vary greatly owing to different compositions of feedstock. In the research process, the inventor of the present invention have found that the aromatic hydro-saturation depth of the light catalytic cracking cycle oil has a great influence

on the product quality of FCC gasoline. Especially, the monocyclic aromatic hydrocarbons in gasoline are a high-octane number component, and the octane number of FCC gasoline can be increased by increasing the content of monocyclic aromatic hydrocarbons in the hydrogenated light catalytic cracking cycle oil. Through further research, the inventor of the present invention has found that the content of monocyclic aromatic hydrocarbons in the follow-up product can be increased by extracting the gas-phase stream from a part of the first hydro-treated stream, possibly because that the extracted gas-phase stream contains hydrogen sulfide and ammonia at certain concentration and attains an inhibiting effect equivalent to decreasing the activity of the catalyst. Thus, under hydrofining conditions, the hydrogenation depth of the light catalytic cracking cycle oil can be controlled precisely, and the bicyclic aromatic hydrocarbons and polycyclic aromatic hydrocarbons in the light catalytic cracking cycle oil can be hydrogenated into monocyclic aromatic hydrocarbons on a premise of meeting the sulfur content requirement, rather than over-hydrogenated to produce naphthenic hydrocarbons or under-hydrogenated to produce bicyclic aromatic hydrocarbons. Thus, when the hydro-fined product is returned to the FCC unit, the content of aromatic hydrocarbons in the FCC gasoline can be increased, and thereby the octane number of the FCC gasoline can be improved. In addition, the process provided by the present invention reduces the adverse effects of hydrogen sulfide and ammonia on the second hydro-treating catalyst, and is more favorable for improving the service life of the second hydro-treating catalyst.

Compared with the prior art, the wax oil hydrogenation method and system provided in the present invention have the following advantages:

1. In the present invention, at least two steps of hydro-treatment are executed, and a step of gas-liquid separation and extraction of a part of hydro-treated gas-phase stream is carried out between the two steps of hydro-treatment to realize effective allocation of the hydro-treated streams, then the obtained streams are treated through a combined hydrogenation process, so that target products of different specifications can be produced as required. In contrast, in the prior art, the hydrofining technique and the hydro-treating technique are used separately, and consequently usually only one hydrogenated target product can be obtained.

2. In the present invention, gas-liquid separation is carried out between the two steps of hydro-treatment, a hydro-treated gas-phase streams obtained through hydro-treatment of the wax oil is extracted, mixed with the light catalytic cracking cycle oil, and the resultant mixture is fed for separate hydrofining reaction. Since the extracted gas-phase stream contains hydrogen sulfide and ammonia, it is adverse to the hydro-desulfurization reaction of the light catalytic cracking cycle oil and attains an inhibiting effect that is equivalent to decreasing the activity of the catalyst. Under

hydrofining conditions, the hydrofining depth of the light catalytic cracking cycle oil is controlled precisely, and the bicyclic aromatic hydrocarbons and polycyclic aromatic hydrocarbons in the light catalytic cracking cycle oil are hydrogenated into monocyclic aromatic hydrocarbons on a premise of meeting the sulfur content requirement, rather than over-hydrogenated to produce naphthenic hydrocarbons or under-hydrogenated to produce bicyclic aromatic hydrocarbons. Thus, when the hydro-fined product is returned to the FCC unit, the content of aromatic hydrocarbons in the FCC gasoline can be increased, and thereby the octane number of the FCC gasoline can be improved; as for the hydro-treating part, since the hydrogen sulfide and ammonia components produced through hydro-desulfurization and hydro-denitrification reactions in the first hydro-treating process are extracted and the remaining stream is mixed with hydrogen-containing gas, it is equivalent to decreasing the partial pressure of hydrogen sulfide and the partial pressure of ammonia in the second hydro-treating process, i.e. reducing the inhibition on the active sites of the follow-up hydro-treating catalyst or improving the activity of the second hydro-treating catalyst and decreasing the severity of the second hydro-treating operation.

3. In the present invention, the gas-phase stream extracted between two steps of hydro-treatment has high temperature and high pressure, and can be mixed with the light catalytic cracking cycle oil after heat exchange and then directly have the separate hydrofining reaction; thus, the heat carried by the hydro-treated gas-phase stream can be fully utilized to realize coupled operation of hydro-treatment and hydrofining.

4. In the present invention, the operating pressure of the hydro-treating reaction system and the operating pressure of the hydrofining reaction system may be the same, and the hydro-treating reaction system and the hydrofining reaction system may share one separation and fractionation unit; thus, the equipment investment and operation cost can be saved greatly.

Brief Description of Drawings

Fig. 1 is a schematic diagram of the wax oil hydrogenation system provided in Example 1 of the present invention;

Fig. 2 is a schematic diagram of the wax oil hydrogenation system provided in Example 4 of the present invention;

Fig. 3 is a schematic diagram of the wax oil hydrogenation system provided in Example 5 of the present invention.

Description of the Symbols of the Drawings

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| 1. first hydro-treating unit | 2. gas-liquid separator |
| 3. second hydro-treating unit | 4. light catalytic cracking cycle oil supply unit |
| 5. hydrofining unit | 51. first hydrofining unit |
| 52. second hydrofining unit | 61. hydro-treating high-pressure separator |
| 62. hydro-treating low-pressure separator | 7. hydro-treating fractionation tower |
| 81. hydrofining high-pressure separator | 82. hydrofining low-pressure separator |
| 9. hydrofining fractionation tower | 101. mixing high-pressure separator |
| 102. mixing low-pressure separator | 11. mixing fractionation tower |
| 12. light catalytic cracking cycle oil fractionation tower | |

Detailed Description of the Embodiments

The ends points and any value in the ranges disclosed in the present invention are not limited to the exact ranges or values; instead, those ranges or values shall be comprehended as encompassing values that are close to those ranges or values. For numeric ranges, the end points of the ranges, the end points of the ranges and the discrete point values, and the discrete point values may be combined with each other to obtain one or more new numeric ranges, which shall be deemed as having been disclosed specifically in this document.

In a first aspect, the present invention provides a wax oil hydrogenation method, which comprises the following steps:

(1) controlling wax oil as feedstock and a hydrogen-containing gas to contact with a first hydro-treating catalyst under first hydro-treating conditions, dividing a first hydro-treated stream obtained through the contact into two parts, i.e., a first hydro-treated stream **A** and a first hydro-treated stream **B**, and performing gas-liquid separation of the first hydro-treated stream **A** to obtain a first hydro-treated gas-phase stream and a first hydro-treated liquid-phase stream;

(2) controlling the first hydro-treated stream **B**, the first hydro-treated liquid-phase stream, and a hydrogen-containing gas to contact with a second hydro-treating catalyst under second hydro-treating conditions, to obtain a resultant hydro-treated stream; and

(3) controlling the first hydro-treated gas-phase stream and light catalytic cracking cycle oil to contact with a hydrofining catalyst to have a hydrofining reaction under hydrofining conditions, to obtain a resultant hydro-fined stream.

According to the present invention, preferably, the initial boiling point of the wax oil is 100-400°C,

and the final boiling point of the wax oil is 405-650°C. For example, the initial boiling point of the wax oil is 320-345°C, and the final boiling point of the wax oil is 550-620°C.

The wax oil may be selected from at least one of vacuum gas oil (VGO), coker gas oil (CGO), deasphalted oil (DAO), coal tar, direct coal liquefaction distillate (DCLD), indirect coal liquefaction distillate (ICLD), synthetic oil, and shale oil.

The hydrogen-containing gas refers to a gas that can provide hydrogen, and may be fresh hydrogen, recycled hydrogen, or hydrogen-rich gas. The hydrogen-containing gas in the step (1) and the hydrogen-containing gas in the step (2) in the present invention may be the same or different from each other. Those skilled in the art can clearly understand the hydrogen-containing gas in the present invention after learning about the technical scheme of the present invention.

According to the present invention, the first hydro-treating catalyst and the second hydro-treating catalyst may be various hydro-treating catalysts that are conventionally used in the art; preferably, the first hydro-treating catalyst and the second hydro-treating catalyst contain a carrier and an active component respectively and independently, the active component is selected from at least one of VIB and/or VIII metal elements, and the carrier is alumina and/or silicon-containing alumina. The VIB metal element usually is Mo and/or W, and the VIII metal element usually is Co and/or Ni.

Preferably, based on the total weight of the first hydro-treating catalyst and measured in oxide, the content of the VIB metal element is 10-35wt%, and the content of the VIII metal element is 3-15wt%. Further preferably, the specific surface area of the first hydro-treating catalyst is 100-650m²/g, and the pore volume of the first hydro-treating catalyst is 0.15-0.6mL/g.

Preferably, based on the total weight of the second hydro-treating catalyst and measured in oxide, the content of the VIB metal element is 10-35wt%, and the content of the VIII metal element is 3-15wt%. Further preferably, the specific surface area of the second hydro-treating catalyst is 100-650m²/g, and the pore volume of the second hydro-treating catalyst is 0.15-0.6mL/g.

The first hydro-treating catalyst and the second hydro-treating catalyst may be purchased commercially or prepared. The first hydro-treating catalyst and the second hydro-treating catalyst in the present invention respectively and independently include, but are not limited to: hydro-treating catalysts 3936, 3996, FF-16, FF-24, FF-26, FF-36, FF-46, and FF-56 developed by Sinopec Dalian (Fushun) Research Institute of Petroleum and Petrochemicals, catalysts HC-K and HC-P from UOP, catalysts TK-555 and TK-565 from Topsoe, and catalysts KF-847 and KF-848 from Akzo.

The first hydro-treating catalyst and the second hydro-treating catalyst in the present invention may

be the same or different from each other.

The first hydro-treating conditions and the second hydro-treating conditions may be conventional operating conditions. For example, the first hydro-treating conditions and the second hydro-treating conditions respectively and independently include: reaction pressure: 3-19MPa, reaction temperature: 300-450°C, liquid hourly space velocity: 0.2-6h⁻¹, and volume ratio of hydrogen to oil: 100-2,000:1; preferably, the first hydro-treating conditions and the second hydro-treating conditions respectively and independently include: reaction pressure: 4-17MPa; reaction temperature: 320-420°C, liquid hourly space velocity: 0.4-4h⁻¹, and volume ratio of hydrogen to oil: 400-1,500:1, further preferably, the first hydro-treating conditions and the second hydro-treating conditions respectively and independently include: reaction pressure: 6-17MPa; reaction temperature: 350-385°C, liquid hourly space velocity: 0.8-4h⁻¹, and volume ratio of hydrogen to oil: 700-1,500:1. The first hydro-treating conditions and the second hydro-treating conditions may be the same or different.

According to the present invention, to protect the first hydro-treating catalyst better, preferably the method further comprises: controlling the wax oil to contact with a hydroprocessing guard catalyst first and contact with the first hydro-treating catalyst then. That preferred embodiment is more favorable for prolonging the service life of the first hydro-treating catalyst. Specifically, the hydroprocessing guard catalyst may be charged on the top of the bed layer of the first hydro-treating catalyst. There is no particular requirement for the hydroprocessing guard catalyst in the present invention. In other words, the hydroprocessing guard catalyst may be any hydroprocessing guard catalyst that is conventionally used in the art, such as the FZC series catalysts developed by Sinopec Dalian (Fushun) Research Institute of Petroleum and Petrochemicals, including FZC-100, FZC-105, and FZC-106. To improve the effect of the hydroprocessing guard catalyst, two or more hydroprocessing guard catalysts blended together may be used as the hydroprocessing guard catalyst. Those skilled in the art can select the hydroprocessing guard catalyst appropriately according to the actual conditions.

According to the present invention, the operating conditions of the hydroprocessing guard catalyst may be conventional operating conditions. For example, the reaction pressure may be 3-19MPa, the reaction temperature may be 280-420°C, the liquid hourly space velocity may be 0.5-20h⁻¹, and the volume ratio of hydrogen to oil may be 100-2,000:1.

According to a preferred embodiment of the present invention, the first hydro-treated stream **A** accounts for 5-95wt% of the total weight of the first hydro-treated stream **A** and the first hydro-treated stream **B**, further preferably is 10-80wt%, still further preferably is 22-53wt%.

According to the present invention, the gas-liquid separation of the first hydro-treated stream **A** may be carried out in a gas-liquid separator. There is no particular restriction on the conditions of the gas-liquid separation in the present invention. That is to say, the gas-liquid separation may be carried out with conventional technical means in the art. The gas-liquid separator at least comprises a reactant inlet, a liquid phase conduit, and a gas phase conduit. Specifically, the first hydro-treated gas-phase stream obtained through the separation is extracted through the gas phase conduit, and the first hydro-treated liquid-phase stream obtained through the separation is led through the liquid phase conduit to the unit for the second hydro-treating reaction.

According to a preferred embodiment of the present invention, the hydro-treated gas-phase stream accounts for 5-95vol% of the hydrogen-containing gas in the step (1), preferably is 10-80vol%, further preferably is 20-50vol%.

According to the present invention, there is no particular restriction on the light catalytic cracking cycle oil (LCO). In other words, the light catalytic cracking cycle oil may be any light catalytic cracking cycle oil conventionally used in the art. For example, the initial boiling point of the light catalytic cracking cycle oil is 100-200°C, and the final boiling point of the light catalytic cracking cycle oil is 320-400°C. The Examples of the present invention are described exemplarily with light catalytic cracking cycle oil within 156-380°C fraction range.

According to method provided in the present invention, the light catalytic cracking cycle oil may further contain at least one of light coker gas oil, ethylene cracked tar, and coal tar. Such an embodiment can widen the sources of diesel oil raw materials that contain rich aromatic hydrocarbons.

According to the method provided in the present invention, preferably, the weight ratio of the light catalytic cracking cycle oil to the wax oil is 0.1-3:1, more preferably is 0.3-1.1:1.

According to the present invention, the hydrofining catalyst may be any hydrofining catalyst conventionally used in the art. Preferably, the hydrofining catalyst contains a carrier and an active component, wherein, the active component is selected from at least one of VIB and/or VIII metal elements, and the carrier is alumina and/or silicon-containing alumina. The VIB metal element usually is Mo and/or W, and the VIII metal element usually is Co and/or Ni. Preferably, based on the total weight of the hydrofining catalyst and measured in oxide, the content of the VIB metal element is 10-35wt%, and the content of the VIII metal element is 3-15wt%. Further preferably, the specific surface area of the hydrofining catalyst is 100-650m²/g, and the pore volume of the hydro-treating catalyst is 0.15-0.6mL/g.

The hydrofining catalyst may be purchased commercially or prepared. The hydrofining catalyst in the present invention includes, but is not limited to: catalysts 3936, FF-14, FF-16, FF-24, FF-26, FF-36, FF-56, FHUDES-5, and FHUDES-7 developed by Sinopec Dalian (Fushun) Research Institute of Petroleum and Petrochemicals, catalysts HC-K and HC-P from UOP, catalysts TK-555 and TK-565 from Topsoe, and catalysts KF-847 and KF-848 from Akzo.

According to the present invention, the hydrofining conditions include: the reaction pressure may be 3-19MPa, the reaction temperature may be 260-450°C, the liquid hourly space velocity may be 0.2-6h⁻¹, the volume ratio of hydrogen to oil may be 100-2,000:1, and preferably the reaction temperature is 280-410°C; further preferably, the hydrofining conditions include: reaction pressure: 4-17MPa, reaction temperature: 300-400°C, liquid hourly space velocity: 0.5-5h⁻¹, and volume ratio of hydrogen to oil: 300-1,500:1, more further preferably, the hydrofining conditions include: reaction pressure: 6-17MPa, reaction temperature: 340-375°C, liquid hourly space velocity: 1.5-5h⁻¹, and volume ratio of hydrogen to oil: 1,000-1,500:1.

According to a preferred embodiment of the present invention, the method further comprises cutting the light catalytic cracking cycle oil to obtain a light fraction and a heavy fraction, wherein the cutting temperature is 245-300°C, further preferably is 260-280°C; the step (3) comprises: controlling the first hydro-treated gas-phase stream, the heavy fraction, and a hydrogen-containing gas to contact with a first hydrofining catalyst to have a first hydrofining reaction under first hydrofining conditions, to obtain a first hydro-fined stream; then controlling the first hydro-fined stream, the light fraction, and a hydrogen-containing gas to contact with a second hydrofining catalyst to have a second hydrofining reaction under second hydrofining conditions.

Still further preferably, the temperature of the second hydrofining reaction is lower than the temperature of the first hydrofining reaction; preferably, the temperature of the second hydrofining reaction is lower than the temperature of the first hydrofining reaction by 5-20°C; more preferably, the temperature of the second hydrofining reaction is lower than the temperature of the first hydrofining reaction by 10-20°C.

The heavy fraction obtained by cutting the raw light catalytic cracking cycle oil are mainly polycyclic aromatic hydrocarbons, which undergo twice hydrofining reactions, and are more favorable to attain the purpose of controlling the aromatic hydrogenation depth; the bicyclic aromatic hydrocarbons in the light fraction obtained by cutting the light catalytic cracking cycle oil undergo less (once) hydrofining reaction, and can be used with the heavy fraction of the light catalytic cracking cycle oil to further attain the purpose of controlling the aromatic hydrogenation depth;

namely, the bicyclic aromatic hydrocarbons and polycyclic aromatic hydrocarbons in the hydro-fined light catalytic cracking cycle oil are hydrogenated moderately into monocyclic aromatics on a premise of meeting the sulfur content requirement, and the monocyclic aromatics is further treated by FCC to obtain catalytic gasoline that meets the sulfur content requirement and has improved octane number.

Furthermore, in a preferred embodiment of the present invention, the temperature of the second hydrofining reaction is lower than the temperature of the first hydrofining reaction by 5-20°C (more preferably 10-20°C), and is more favorable for the reaction of hydro-saturation of bicyclic aromatic hydrocarbons into monocyclic aromatic hydrocarbons.

According to a preferred embodiment of the present invention, the first hydrofining conditions and the second hydrofining conditions respectively and independently include: reaction pressure: 4-17MPa, reaction temperature: 300-400°C, liquid hourly space velocity: 0.5-5h⁻¹, and volume ratio of hydrogen to oil: 300-1,500:1; preferably, the first hydrofining conditions and the second hydrofining conditions respectively and independently include: reaction pressure: 6-17MPa, reaction temperature: 340-385°C, liquid hourly space velocity: 1.5-5h⁻¹, and volume ratio of hydrogen to oil: 1,000-1,500:1.

Preferably, the temperature of the first hydrofining reaction is 340-395°C, and the temperature of the second hydrofining reaction is 320-385 °C, further preferably, the temperature of the first hydrofining reaction is 355-375°C, and the temperature of the second hydrofining reaction is 340-365°C.

Further preferably, the liquid hourly space velocity of the first hydrofining reaction is 0.5-5.0h⁻¹ (preferably 1.0-4.0h⁻¹, further preferably 1.5-2.1h⁻¹), and the liquid hourly space velocity of the second hydrofining reaction is 1.0-6.0h⁻¹ (preferably 1.5-5.0h⁻¹, further preferably 3.3-4.5h⁻¹).

According to the present invention, the first hydro-treatment in the step (1) and the second hydro-treatment in the step (2) may be carried out in one hydrogenation reactor or in two hydrogenation reactors. Specifically, in the case that the first hydro-treatment in the step (1) and the second hydro-treatment in the step (2) are carried out in one hydrogenation reactor, a first hydro-treating catalyst bed layer and a second hydro-treating catalyst bed layer are arranged sequentially in the hydrogenation reactor, and a gas-liquid separator may be arranged between the first hydro-treating catalyst bed layer and the second hydro-treating catalyst bed layer to carry out the gas-liquid separation. In the case that the hydro-treatment in the step (1) and the second

hydro-treatment in the step (2) are carried out in two hydrogenation reactors, the first hydro-treatment in the step (1) may be carried out in a first hydro-treating reactor, and the second hydro-treatment in the step (2) may be carried out in a second hydro-treating reactor, the first hydro-treating reactor and the second hydro-treating reactor are arranged in series, and a gas-liquid separator may be arranged between the first hydro-treating reactor and the second hydro-treating reactor to carry out the gas-liquid separation.

According to the present invention, the hydrofining in the step (3) may be carried out in a hydrofining reactor in which a hydrofining catalyst bed layer is provided. Furthermore, preferably the hydrofining reaction in the step (3) comprises a first hydrofining reaction and a second hydrofining reaction. The first hydrofining reaction and the second hydrofining reaction may be carried out in one hydrogenation reactor or two hydrogenation reactors. Specifically, in the case that the first hydrofining reaction and the second hydrofining reaction are carried out in one hydrogenation reactor, a first hydrofining catalyst bed layer and a second hydrofining catalyst bed layer are arranged sequentially in the hydrogenation reactor. In the case that the first hydrofining reaction and the second hydrofining reaction are carried out in two hydrogenation reactors, the first hydrofining reaction may be carried out in a first hydrofining reactor, the second hydrofining reaction may be carried out in a second hydrofining reactor, and the first hydrofining reactor and the second hydrofining reactor are arranged in series.

According to the method provided in the present invention, those skilled in the art can perform separation and fractionation for the resultant hydro-treated stream obtained in the step (2) and the resultant hydro-fined stream obtained in the step (3) according to specific requirements, to obtain specific target products.

According to the method provided in the present invention, preferably, the step (2) further comprises: treating the resultant hydro-treated stream by separation and fractionation to obtain a hydro-treated hydrogen-rich gas, a hydro-treated gas, a hydro-treated naphtha, a hydro-treated diesel oil, and a hydro-treated heavy fraction; further preferably, the separation in the step (2) comprises high-pressure separation and low-pressure separation, the resultant hydro-treated stream is treated by high-pressure separation to obtain the hydro-treated hydrogen-rich gas and a hydro-treated high-pressure separated liquid-phase stream, and then the hydro-treated high-pressure separated liquid-phase stream is treated by low-pressure separation to obtain the hydro-treated gas and a hydro-treated liquid-phase stream, and the hydro-treated liquid-phase stream is treated by fractionation to obtain the hydro-treated naphtha, the hydro-treated diesel oil, and the hydro-treated heavy fraction. The high-pressure separation may be carried out in a high-pressure separator, and the

low-pressure separation may be carried out in a low-pressure separator. There is no particular restriction on the conditions of the high-pressure separation and the conditions of the low-pressure separation in the present invention. That is to say, the high-pressure separation and the low-pressure separation may be carried out with conventional technical means in the art.

- 5 Those skilled in the art can carry out fractionation specifically for the hydro-treated liquid-phase stream according to specific requirements for the products. The fractionation in the step (2) in the present invention may be carried out in a hydro-treating fractionation tower, and there is no particular restriction on the conditions of the fractionation in the step (2), as long as the above-mentioned products can be obtained. For example, the above-mentioned products can be obtained through the
10 fractionation, wherein, the initial boiling point of the hydro-treated naphtha may be 35-45°C, the cutting temperature between the hydro-treated naphtha and the hydro-treated diesel oil may be 60-180°C, and the cutting temperature between the hydro-treated diesel oil and the hydro-treated heavy fraction may be 330-375°C.

- According to the method provided in the present invention, preferably, the step (3) further comprises:
15 treating the resultant hydro-fined stream by separation and fractionation to obtain a hydro-fined hydrogen-rich gas, a hydro-fined gas, a hydro-fined naphtha, and a hydro-fined diesel oil; further preferably, the separation in the step (3) comprises high-pressure separation and low-pressure separation, the resultant hydro-fined stream is treated by high-pressure separation to obtain the hydro-fined hydrogen-rich gas and a hydro-fined high-pressure separated liquid-phase stream, and
20 then the hydro-fined high-pressure separated liquid-phase stream is treated by low-pressure separation to obtain the hydro-fined gas and a hydro-fined liquid-phase stream, and the hydro-fined liquid-phase stream is treated by fractionation to obtain the hydro-fined naphtha and the hydro-fined diesel oil. The high-pressure separation may be carried out in a high-pressure separator, and the low-pressure separation may be carried out in a low-pressure separator. There is no particular
25 restriction on the conditions of the high-pressure separation and the conditions of the low-pressure separation in the present invention. That is to say, the high-pressure separation and the low-pressure separation may be carried out with conventional technical means in the art.

- Those skilled in the art can carry out fractionation specifically for the hydro-fined liquid-phase stream according to specific requirements for the products. The fractionation in the step (3) in the
30 present invention may be carried out in a hydrofining fractionation tower, and there is no particular restriction on the conditions of the fractionation in the step (3), as long as the above-mentioned products can be obtained. For example, the above-mentioned products can be obtained through the

fractionation, wherein, the initial boiling point of the hydro-fined naphtha may be 35-45°C, and the cutting temperature between the hydro-fined naphtha and the hydro-fined diesel oil may be 60-180 °C.

In the present invention, both the hydro-treated gas and the hydro-fined gas are hydrocarbon-rich gases. In addition, the gases may be separated according to the actual requirement to obtain desired gas products.

According to a preferred embodiment of the present invention, the method further comprises: recycling the hydro-treated hydrogen-rich gas and the hydro-fined hydrogen-rich gas to provide required hydrogen-containing gas. The hydro-treated hydrogen-rich gas and the hydro-fined hydrogen-rich gas may be directly recycled or recycled after desulphurization.

The hydro-treated hydrogen-rich gas and the hydro-fined hydrogen-rich gas may be respectively and independently recycled and reused in the step (1) and/or the step (2); in addition, make-up hydrogen may be introduced if the hydro-treated hydrogen-rich gas and the hydro-fined hydrogen-rich gas are not enough to hydrogen required by the method provided in the present invention. Those skilled in the art can clearly understand how to recycle the hydro-treated hydrogen-rich gas and the hydro-fined hydrogen-rich gas after learning about the technical scheme of the present invention.

The concentration of hydrogen in the hydro-treated hydrogen-rich gas and the hydro-fined hydrogen-rich gas is high, and the concentration of the hydrogen-containing gas is higher and usually can reach 85-97vol% after the hydro-treated hydrogen-rich gas and the hydro-fined hydrogen-rich gas are mixed with the make-up hydrogen.

To further simplify the apparatus, preferably the hydro-treated hydrogen-rich gas and the hydro-fined hydrogen-rich gas obtained through the high-pressure separation in the step (1) and the high-pressure separation in the step (2) are at the same pressure. With that preferred embodiment, the hydro-treated hydrogen-rich gas and the hydro-fined hydrogen-rich gas may be recycled with one system.

The hydro-treated gas obtained in the step (2) and the hydro-fined gas obtained in the step (3) may be taken as products separately, or may be mixed to obtain a mixed gas product.

The hydro-treated naphtha obtained in the step (2) and the hydro-fined naphtha obtained in the step (3) may be taken as products separately, or may be mixed to obtain a mixed naphtha product.

The hydro-treated diesel oil obtained in the step (2) and the hydro-fined diesel oil obtained in the step (3) may be taken as products separately, or may be mixed to obtain a mixed diesel oil product.

The hydro-treated heavy fraction obtained in the step (2) may be used as feedstock for a FCC unit.

According to the present invention, to further save equipment investment and operation cost, preferably the method further comprises: mixing the resultant hydro-treated stream and the resultant hydro-fined stream to obtain a mixture flow, and then performing separation (preferably including high-pressure separation and low-pressure separation) and fractionation for the mixture flow; further
5 preferably, the mixture flow is separated by high-pressure separation to obtain a mixed hydrogen-rich gas and a mixed high-pressure separated liquid-phase stream, and then the mixed high-pressure separated liquid-phase stream is separated by low-pressure separation to obtain a mixed gas and a mixed liquid-phase stream, and the mixed liquid-phase stream is fractionated to obtain a mixed naphtha, a mixed diesel oil, and a mixed heavy fraction. The high-pressure separation may be carried
10 out in a high-pressure separator, and the low-pressure separation may be carried out in a low-pressure separator. There is no particular restriction on the conditions of the high-pressure separation and the conditions of the low-pressure separation in the present invention. That is to say, the high-pressure separation and the low-pressure separation may be carried out with conventional technical means in the art.

Those skilled in the art can carry out fractionation specifically for the mixed liquid-phase stream according to specific requirements for the products. The fractionation may be carried out in a mixing fractionation tower, and there is no particular restriction on the conditions of the fractionation in the present invention, as long as the above-mentioned products can be obtained. For example, the initial boiling point of the mixed naphtha may be 35-45°C, the cutting temperature between the mixed
20 naphtha and the mixed diesel oil may be 60-180°C, and the cutting temperature between the mixed diesel oil and the mixed heavy fraction may be 330-375°C.

The mixed gas is a hydrocarbon-rich gas. In addition, the gas may be separated according to the actual requirement to obtain desired gas products.

According to a preferred embodiment of the present invention, the method further comprises:
25 recycling the mixed hydrogen-rich gas to provide required hydrogen-containing gas. The mixed hydrogen-rich gas may be directly recycled, or may be recycled after desulphurization.

In a second aspect, the present invention provides a wax oil hydrogenation system. As shown in Figs. 1, 2, and 3, the wax oil hydrogenation system comprises:

a first hydro-treating unit 1;

30 a gas-liquid separator 2 configured to perform gas-liquid separation for a part of first hydro-treated stream obtained in the first hydro-treating unit 1 to obtain a first hydro-treated gas-phase stream and

a first hydro-treated liquid-phase stream;

a second hydro-treating unit 3 configured to perform second hydro-treatment for the remaining part of the first hydro-treated stream and the first hydro-treated liquid-phase stream in it to obtain a resultant hydro-treated stream;

5 a light catalytic cracking cycle oil supply unit 4 configured to supply light catalytic cracking cycle oil; and

a hydrofining unit 5 configured to perform hydrofining for the light catalytic cracking cycle oil supplied by the light catalytic cracking cycle oil supply unit 4 and the hydro-treated gas-phase stream in it to obtain a resultant hydro-fined stream.

10 In the present invention, there is no particular restriction on the light catalytic cracking cycle oil supply unit 4, as long as it can supply light catalytic cracking cycle oil. The light catalytic cracking cycle oil supply unit 4 may be a light catalytic cracking cycle oil storage tank or an apparatus for producing light catalytic cracking cycle oil.

According to the present invention, the outlet of the light catalytic cracking cycle oil supply unit 4
15 communicates with the inlet of the hydrofining unit 5 through a pipeline.

According to the system provided in the present invention, preferably, the gas-liquid separator 2 comprises a reactant inlet, a liquid phase conduit, and a gas phase conduit; the reactant inlet of the gas-liquid separator 2 communicates with the outlet of the first hydro-treating unit 1, the first hydro-treated liquid-phase stream is led into the second hydro-treating unit 3 through the liquid
20 phase conduit, and the first hydro-treated gas-phase stream is led into the hydrofining unit 5 through the gas phase conduit. A part of the first hydro-treated stream obtained in the first hydro-treating unit 1 is treated by gas liquid separation in the gas-liquid separator 2 to obtain a first hydro-treated gas-phase stream and a first hydro-treated liquid-phase stream; the first hydro-treated liquid-phase stream is led through the liquid phase conduit to the second hydro-treating unit and is treated
25 together with the remaining part of the first hydro-treated stream by second hydro-treating in the second hydro-treating unit 3; the first hydro-treated gas-phase stream is led through the gas phase conduit to the hydrofining unit 5 and is treated together with the light catalytic cracking cycle oil supplied by the light catalytic cracking cycle oil supply unit 4 by hydrofining in the hydrofining unit 5.

30 According to the system provided in the present invention, there is no particular restriction on the arrangement of the first hydro-treating unit 1 and the second hydro-treating unit 3. According to an embodiment of the present invention, the first hydro-treating unit 1 and the second hydro-treating

unit 3 may be arranged in one hydrogenation reactor; according to another embodiment of the present invention, the first hydro-treating unit 1 and the second hydro-treating unit 3 may be arranged in different hydrogenation reactors respectively.

According to a preferred embodiment of the present invention, the hydrofining unit 5 comprises a first hydrofining unit 51 and a second hydrofining unit 52 that are arranged in series, and the system further comprises: a light catalytic cracking cycle oil fractionation tower 12 arranged between the first hydrofining unit 51 and the light catalytic cracking cycle oil supply unit 4 to cut the light catalytic cracking cycle oil supplied by the light catalytic cracking cycle oil supply unit 4 into a light fraction and a heavy fraction; the heavy fraction and the first hydro-treated gas-phase stream are hydro-fined in the first hydrofining unit 51 to obtain a first hydro-fined stream; the first hydro-fined stream and the light fraction are hydro-fined in the second hydrofining unit 52 to obtain the resultant hydro-fined stream.

Specifically, the inlet of the light catalytic cracking cycle oil fractionation tower 12 communicates with the outlet of the light catalytic cracking cycle oil supply unit 4 through a pipeline, the light catalytic cracking cycle oil supplied by the light catalytic cracking cycle oil supply unit 4 is fed into the light catalytic cracking cycle oil fractionation tower 12 and fractionated there, to obtain the light fraction and the heavy fraction. The light catalytic cracking cycle oil fractionation tower 12 has a light fraction outlet and a heavy fraction outlet, the heavy fraction outlet of the light catalytic cracking cycle oil fractionation tower 12 communicates with the inlet of the first hydrofining unit 51, and the light fraction outlet of the light catalytic cracking cycle oil fractionation tower 12 communicates with the inlet of the second hydrofining unit 52.

According to the present invention, the first hydrofining unit 51 and the second hydrofining unit 52 may be arranged in one hydrogenation reactor or arranged in different hydrogenation reactors respectively. Preferably, the first hydrofining unit 51 and the second hydrofining unit 52 are arranged in one hydrogenation reactor.

With the preferred embodiment, the bicyclic aromatic hydrocarbons and polycyclic aromatic hydrocarbons in the hydro-fined light catalytic cracking cycle oil can be hydrogenated moderately into monocyclic aromatic hydrocarbons more easily on a premise of meeting the sulfur content requirement, and then the monocyclic aromatic hydrocarbons can be further treated by catalytic cracking to obtain FCC gasoline that meets the sulfur content requirement and has improved octane number.

According to the system provided in the present invention, those skilled in the art can perform

separation and fractionation for the resultant hydro-treated stream obtained in the second hydro-treating unit 3 and the resultant hydro-fined stream obtained in the hydrofining unit 5 according to specific requirements, to obtain specific target products.

According to an embodiment of the present invention, the resultant hydro-treated stream and the resultant hydro-fined stream are treated by separation and fractionation respectively.

Preferably, the system provided in the present invention further comprises:

a hydro-treating separation unit comprising a hydro-treating high-pressure separator 61 and a hydro-treating low-pressure separator 62 that are connected in series, wherein, the outlet of the second hydro-treating unit 3 communicates with the inlet of the hydro-treating high-pressure separator 61 through a pipeline; the resultant hydro-treated stream is separated at a high pressure in the hydro-treating high-pressure separator 61 to obtain a hydro-treated hydrogen-rich gas and a hydro-treated high-pressure separated liquid-phase stream, and then the hydro-treated high-pressure separated liquid-phase stream is separated at a low pressure in the hydro-treating low-pressure separator 62 to obtain a hydro-treated gas and a hydro-treated liquid-phase stream.

Preferably, the system provided in the present invention further comprises: a hydro-treating fractionation tower 7, wherein the inlet of the hydro-treating fractionation tower 7 communicates with the outlet of the hydro-treating low-pressure separator 62 through a pipeline, the hydro-treated liquid-phase stream is fractionated in the hydro-treating fractionation tower 7 to obtain a hydro-treated naphtha, a hydro-treated diesel oil, and a hydro-treated heavy fraction.

Preferably, the system provided in the present invention further comprises: a hydrofining separation unit comprising a hydrofining high-pressure separator 81 and a hydrofining low-pressure separator 82 that are connected in series, wherein, the outlet of the hydrofining unit 5 communicates with the inlet of the hydrofining high-pressure separator 81 through a pipeline; the resultant hydro-fined stream is separated at a high pressure in the hydrofining high-pressure separator 81 to obtain a hydro-fined hydrogen-rich gas and a hydro-fined high-pressure separated liquid-phase stream, and then the hydro-fined high-pressure separated liquid-phase stream is separated at a low pressure in the hydrofining low-pressure separator 82 to obtain a hydro-fined gas and a hydro-fined liquid-phase stream.

Preferably, the system provided in the present invention further comprises: a hydrofining fractionation tower 9, wherein the inlet of the hydrofining fractionation tower 9 communicates with the outlet of the hydrofining low-pressure separator 82 through a pipeline, the hydro-fined liquid-phase stream is fractionated in the hydrofining fractionation tower 9 to obtain a hydro-fined

naphtha and a hydro-fined diesel oil.

There is no particular restriction on the hydro-treating high-pressure separator 61 and the hydrofining high-pressure separator 81 in the present invention; in other words, they may be high-pressure separators conventionally used in the art. Likewise, there is no particular restriction on the hydro-treating low-pressure separator 62 and the hydrofining low-pressure separator 82; in other words, they may be low-pressure separators conventionally used in the art.

There is no particular restriction on the hydro-treating fractionation tower 7 in the present invention, as long as the above-mentioned products can be obtained through fractionation. Those skilled in the art can fractionate the hydro-treated liquid-phase stream specifically according to specific requirements for the products. The products obtained through fractionation of the hydro-treated liquid-phase stream are described above, and will not be further detailed here.

There is no particular restriction on the hydrofining fractionation tower 9 in the present invention, as long as the above-mentioned products can be obtained through fractionation. Those skilled in the art can fractionate the hydro-fined liquid-phase stream specifically according to specific requirements for the products. The products obtained through fractionation of the hydro-fined liquid-phase stream are described above, and will not be further detailed here.

According to a preferred embodiment of the present invention, the gas phase outlet of the hydro-treating high-pressure separator 61 and the gas phase outlet of the hydrofining high-pressure separator 81 communicate with the inlet of the first hydro-treating unit 1 and/or the inlet of the second hydro-treating unit 3 respectively and independently, to recycle the hydro-treated hydrogen-rich gas and the hydro-fined hydrogen-rich gas so as to provide hydrogen required for the system. The specific utilization method is described above, and will not be further detailed here.

According to another embodiment of the present invention, the resultant hydro-treated stream and the resultant hydro-fined stream are mixed to obtain a mixture flow, and then the mixture flow is treated by separation and fractionation. That embodiment is more favorable for reducing equipment investment.

Preferably, the system provided in the present invention further comprises:

a mixing separation unit and a mixing fractionation tower 11, wherein, the mixing separation unit comprises a mixing high-pressure separator 101 and a mixing low-pressure separator 102 that are connected in series, and the outlet of the mixing low-pressure separator 102 communicates with the inlet of the mixing fractionation tower 11; the outlet of the second hydro-treating unit 3 and the outlet of the hydrofining unit 5 communicate with the inlet of the mixing high-pressure separator 101; the

resultant hydro-treated stream and the resultant hydro-fined stream are mixed and then separated at a high pressure in the mixing high-pressure separator 101 to obtain a mixed hydrogen-rich gas and a mixed high-pressure separated liquid-phase stream;

The mixed high-pressure separated liquid-phase stream is separated at a low pressure in the mixing low-pressure separator 102 to obtain a mixed gas and a mixed liquid-phase stream;

The mixed liquid-phase stream is fractionated in the mixing fractionation tower 11 to obtain a mixed naphtha, a mixed diesel oil, and a mixed heavy fraction.

There is no particular restriction on the mixing high-pressure separator 101. In other words, the mixing high-pressure separator 101 may be any high-pressure separator conventionally used in the art. Likewise, there is no particular restriction on the mixing low-pressure separator 102. In other words, the mixing low-pressure separator 102 may be any low-pressure separator conventionally used in the art.

There is no particular restriction on the mixing fractionation tower 7 in the present invention, as long as the above-mentioned products can be obtained through fractionation. Those skilled in the art can fractionate the mixed liquid-phase stream specifically according to specific requirements for the products. The products obtained through fractionation of the mixed liquid-phase stream are described above, and will not be further detailed here.

According to a preferred embodiment of the present invention, the gas-phase outlet of the mixing high-pressure separator 101 communicates with the inlet of the first hydro-treating unit 1 and/or the inlet of the second hydro-treating unit 3 to recycle the mixed hydrogen-rich gas so as to provide hydrogen required for the system. The specific utilization method is described above, and will not be further detailed here.

Hereunder the wax oil hydrogenation method and system in an embodiment of the present invention will be detailed with reference to Fig. 3.

(1) Wax oil and a hydrogen-containing gas are fed into a hydro-treating reactor, which is provided with a first hydro-treating unit 1 (a first hydro-treating catalyst bed layer), a second hydro-treating unit 3 (a second hydro-treating catalyst bed layer), and a gas-liquid separator 2 arranged between the first hydro-treating unit 1 and the second hydro-treating unit 3. A part of a first hydro-treated stream (first hydro-treated stream A) passing through the first hydro-treating catalyst bed layer is separated by gas-liquid separation in the gas-liquid separator 2 to obtain a first hydro-treated gas-phase stream and a first hydro-treated liquid-phase stream;

(2) The remaining part of the first hydro-treated stream (first hydro-treated stream **B**), the first hydro-treated liquid-phase stream, and a hydrogen-containing gas are fed into the second hydro-treating catalyst bed layer to obtain a resultant hydro-treated stream, the resultant hydro-treated stream is fed into a hydro-treating high-pressure separator 61 and separated by high-pressure separation to obtain a hydro-treated hydrogen-rich gas and a hydro-treated high-pressure separated liquid-phase stream, the hydro-treated high-pressure separated liquid-phase stream is fed into a hydro-treating low-pressure separator 62 and separated by low-pressure separation to obtain a hydro-treated gas and a hydro-treated liquid-phase stream; the hydro-treated liquid-phase stream is fractionated in a hydro-treating fractionation tower 7 to obtain a hydro-treated naphtha, a hydro-treated diesel oil, and a hydro-treated heavy fraction;

(3) Light catalytic cracking cycle oil supplied by a light catalytic cracking cycle oil supply unit 4 is cut in a light catalytic cracking cycle oil fractionation tower 12 into a light fraction and a heavy fraction, and the heavy fraction and the first hydro-treated gas-phase stream obtained in the step (1) are fed into a hydrofining unit 5 that is provided with a first hydrofining unit 51 (a first hydrofining catalyst bed layer) and a second hydrofining unit 52 (a second hydrofining catalyst bed layer). The heavy fraction and the first hydro-treated gas-phase stream obtained in the step (1) are fed through the first hydrofining catalyst bed layer to obtain a first hydro-fined stream, and the first hydro-fined stream and the light fraction are fed through the second hydrofining catalyst bed layer to obtain the resultant hydro-fined stream. The resultant hydro-fined stream is fed into a hydrofining high-pressure separator 81 and separated by high-pressure separation to obtain a hydro-fined hydrogen-rich gas and a hydro-fined high-pressure separated liquid-phase stream, and the hydro-fined high-pressure separated liquid-phase stream is fed into a hydrofining low-pressure separator 82 and separated by low-pressure separation to obtain a hydro-fined gas and a hydro-fined liquid-phase stream; the hydro-fined liquid-phase stream is fractionated in a hydrofining fractionation tower 9 to obtain a hydro-fined naphtha and a hydro-fined diesel oil.

The hydro-treated gas obtained in the step (2) and the hydro-fined gas obtained in the step (3) may be taken as products separately, or may be mixed to obtain a mixed gas product. The hydro-treated naphtha obtained in the step (2) and the hydro-fined naphtha obtained in the step (3) may be taken as products separately, or may be mixed to obtain a mixed naphtha product. The hydro-treated diesel oil obtained in the step (2) and the hydro-fined diesel oil obtained in the step (3) may be taken as products separately, or may be mixed to obtain a mixed diesel oil product. The hydro-treated heavy fraction obtained in the step (2) may be used as feedstock for a FCC unit.

The hydro-treated hydrogen-rich gas and the hydro-fined hydrogen-rich gas are recycled and used

together with make-up hydrogen to provide hydrogen-containing gas required for the system.

Hereunder the present invention will be further detailed in examples, but the scope of the present invention is not limited to those examples.

In the following examples, the hydroprocessing guard catalysts are hydroprocessing guard catalysts FZC-100, FZC-105, and FZC-106 developed by Sinopec Dalian (Fushun) Research Institute of Petroleum and Petrochemicals;

The first hydro-treating catalyst and the second hydro-treating catalyst are catalyst FF-24 developed by Sinopec Dalian (Fushun) Research Institute of Petroleum and Petrochemicals;

The hydrofining catalyst is catalyst FHUDES-5 developed by Sinopec Dalian (Fushun) Research Institute of Petroleum and Petrochemicals.

The main properties of the wax oil and the light catalytic cracking cycle oil are listed in Table 1.

Table 1

	Wax oil 1	Wax oil 2	Light catalytic cracking cycle oil
Density, g/cm ³	0.904	0.937	0.935
Fraction range, °C	325-550	345-620	156-380
Sulfur content, wt%	2.2	1.5	1.1
Nitrogen content, wt%	0.103	0.245	0.08
Aromatic content, wt%	—	—	91.6

Examples 1-3

(1) According to the system shown in Fig. 1, wax oil as feedstock and a hydrogen-containing gas are fed into a hydro-treating reactor, which is provided with a first hydro-treating unit 1 (a first hydro-treating catalyst bed layer), a second hydro-treating unit 3 (a second hydro-treating catalyst bed layer), and a gas-liquid separator 2 arranged between the first hydro-treating unit 1 and the second hydro-treating unit 3. A part of a first hydro-treated stream (a first hydro-treated stream **A**) passing through the first hydro-treating catalyst bed layer is separated by gas-liquid separation in the gas-liquid separator 2 to obtain a first hydro-treated gas-phase stream and a first hydro-treated liquid-phase stream. The first hydro-treating conditions are listed in Table 2.

(2) The remaining part of the first hydro-treated stream (a first hydro-treated stream **B**), the first

hydro-treated liquid-phase stream, and a hydrogen-containing gas are fed into the second hydro-treating catalyst bed layer to obtain a resultant hydro-treated stream, the resultant hydro-treated stream is fed into a hydro-treating high-pressure separator 61 and separated by high-pressure separation to obtain a hydro-treated hydrogen-rich gas and a hydro-treated high-pressure separated liquid-phase stream, the hydro-treated high-pressure separated liquid-phase stream is fed into a hydro-treating low-pressure separator 62 and separated by low-pressure separation to obtain a hydro-treated gas and a hydro-treated liquid-phase stream; the hydro-treated liquid-phase stream is fractionated in a hydro-treating fractionation tower 7 to obtain a hydro-treated naphtha (the distillation range is 38-150°C), a hydro-treated diesel oil (the distillation range is 150-365°C), and a hydro-treated heavy fraction (the distillation range is >365°C). The second hydro-treating conditions are listed in Table 2;

(3) The light catalytic cracking cycle oil supplied by a light catalytic cracking cycle oil supply unit 4 and the first hydro-treated gas-phase stream obtained in the step (1) are fed into a hydrofining unit 5 that is provided with a hydrofining catalyst bed layer, and the light catalytic cracking cycle oil and the first hydro-treated gas-phase stream are fed through the hydrofining catalyst bed layer to obtain a resultant hydro-fined stream. The resultant hydro-fined stream is fed into a hydrofining high-pressure separator 81 and separated by high-pressure separation to obtain a hydro-fined hydrogen-rich gas and a hydro-fined high-pressure separated liquid-phase stream, and the hydro-fined high-pressure separated liquid-phase stream is fed into a hydrofining low-pressure separator 82 and separated by low-pressure separation to obtain a hydro-fined gas and a hydro-fined liquid-phase stream; the hydro-fined liquid-phase stream is fractionated in a hydrofining fractionation tower 9 to obtain a hydro-fined naphtha (the distillation range is 38-150°C), and a hydro-fined diesel oil (the distillation range is >150°C). The hydrofining conditions are listed in Table 2.

Wherein, the hydro-treated hydrogen-rich gas and the hydro-fined hydrogen-rich gas are recycled and used together with make-up hydrogen to provide the hydrogen-containing gas (the volume content of hydrogen is about 88-92%) required for the system.

In the Table 2, the FZC series refers to a composite of 10vol% FZC-100, 30vol% FZC-105, and 60vol% FZC-106.

Table 2

	Example 1	Example 2	Example 3
First hydro-treating conditions			

Feedstock	Wax oil 1	Wax oil 1	Wax oil 2
Catalyst	FZC series/FF-24	FZC series/FF-24	FZC series/FF-24
Volume ratio of catalyst	10:90	10:90	15:85
Reaction pressure, MPa	6.0	17.0	12.0
Hydrogen to oil at inlet(v/v)	800:1	1000:1	700:1
Total volumetric space velocity, h ⁻¹	0.8	4.0	2.0
Average reaction temperature, °C	350	385	375
Percent of the first hydro-treated stream A in the first hydro-treated stream, wt%	22	53	38
Volume percent of hydro-treated gas-phase stream in the hydrogen-containing gas at the inlet, %	20	50	35
Second hydro-treating conditions			
Feedstock	First hydro-treated stream B and first hydro-treated liquid-phase stream		
Catalyst	FF-24	FF-24	FF-24
Reaction pressure, MPa	6.0	17.0	12.0
Hydrogen to oil at inlet(v/v)	1000:1	1200:1	1500:1
Volumetric space velocity, h ⁻¹	0.8	4.0	1.6
Average reaction temperature, °C	355	385	370
Hydrofining condition			
Weight ratio of light catalytic cracking cycle oil to wax oil	0.3:1	1.1:1	0.6:1
Catalyst	FHUDS-5	FHUDS-5	FHUDS-5
Reaction pressure, MPa	6.0	17.0	12.0
Hydrogen to oil at inlet(v/v)	1000:1	1200:1	1500:1
Volumetric space velocity, h ⁻¹	1.5	1.6	2.0
Average reaction temperature, °C	355	345	370

The properties of the products obtained in the examples 1-3 are listed in Table 3.

Reference example 1

Wax oil (Wax oil 1) as feedstock and a hydrogen-containing gas are fed into a hydro-treating reactor that is provided with a hydro-treating catalyst bed layer, and the wax oil and the hydrogen-containing gas are fed through the hydro-treating catalyst bed layer for a hydro-treating reaction (the reaction conditions are the same as the first hydro-treating reaction conditions in the example 1) to obtain a hydro-treated stream. The hydro-treated stream is separated in a high-temperature and high-pressure separator to obtain a high-temperature gas phase and a liquid phase.

The high-temperature gas phase obtained through separation in the high-temperature and high-pressure separator is mixed with light catalytic cracking cycle oil (the same as the light catalytic cracking cycle oil in the example 1, the weight ratio of the light catalytic cracking cycle oil to the wax oil is 0.3:1), and then the mixture have a hydrofining reaction (the conditions are the same as the conditions in the example 1) in a hydrofining reactor to obtain a resultant hydro-fined stream. The resultant hydro-fined stream is separated by high-pressure separation and low-pressure separation according to the step (3) in the example 1 to obtain a hydro-fined hydrogen-rich gas, a hydro-fined gas, and a hydro-fined high-pressure separated liquid-phase stream. The hydro-fined high-pressure separated liquid-phase stream is fractionated according to the step (3) in the example 1, to obtain a hydro-fined naphtha and a hydro-fined diesel oil.

The liquid phase obtained through separation in the high-temperature and high-pressure separator is fed into a hydro-treating fractionation tower and fractionated according to the step (2) in the example 1 to obtain a hydro-treated naphtha, a hydro-treated diesel oil, and a hydro-treated heavy fraction.

The properties of the obtained products are listed in Table 3.

Table 3

	Example 1	Reference example 1	Example 2	Example 3
Hydro-treated naphtha				
Sulfur content, $\mu\text{g/g}$	60	62	<0.5	<0.5
Hydro-fined naphtha				
Sulfur content, $\mu\text{g/g}$	15	16	<0.5	<0.5
Hydro-treated diesel oil				
Sulfur content, $\mu\text{g/g}$	400	450	<10	60

Hydro-fined diesel oil				
Sulfur content, $\mu\text{g/g}$	50	60	<10	90
Content of monocyclic aromatic hydrocarbons, wt%	72.0	71.9	74.0	82.9
Hydro-treated heavy fraction				
Sulfur content, $\mu\text{g/g}$	1900	2200	210	680

Example 4

The method described in the example 2 is used, but the resultant hydro-treated stream and the resultant hydro-fined stream are mixed and then separated and fractionated together. Specifically:

- 5 (1) Execute according to the step (1) in the example 2;
- (2) Execute according to the step (2) in the example 2 to obtain a resultant hydro-treated stream;
- (3) Execute according to the step (3) in the example 2 to obtain a resultant hydro-fined stream;
- (4) According to the system shown in Fig. 2, the resultant hydro-treated stream obtained in the step (2) and the resultant hydro-fined stream obtained in the step (3) are mixed to obtain a mixture flow,
- 10 the mixture flow is fed into a mixing high-pressure separator 101 for high-pressure separation to obtain a mixed hydrogen-rich gas and a mixed high-pressure separated liquid-phase stream, the mixed high-pressure separated liquid-phase stream is fed into a mixing low-pressure separator 102 for low-pressure separation to obtain a mixed gas and a mixed liquid-phase stream; the mixed liquid-phase stream is fractionated in a mixing fractionation tower 11 to obtain a mixed naphtha (the
- 15 distillation range is 38-150°C), a mixed diesel oil (the distillation range is 150-365°C), and a mixed heavy fraction (the distillation range is >365°C).

Wherein, the mixed hydrogen-rich gas is recycled and used together with make-up hydrogen to provide hydrogen-containing gas (the volume content of hydrogen is about 88-92%) required for the system.

- 20 The properties of the obtained products are listed in Table 4.

Table 4

	Mixed naphtha	Mixed diesel oil	Mixed heavy fraction
Sulfur content, $\mu\text{g/g}$	<0.5	<10	210

Content of monocyclic aromatic hydrocarbons, wt%	-	61.2	-
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Examples 5-7

(1) According to the system shown in Fig. 3, the first hydro-treatment and the gas liquid separation are carried out according to the examples 1-3. The first hydro-treating conditions are listed in Table 5.

(2) Execute according to the examples 1-3. The second hydro-treating conditions are listed in Table 5;

(3) Light catalytic cracking cycle oil supplied by a light catalytic cracking cycle oil supply unit 4 is cut in a light catalytic cracking cycle oil fractionation tower 12 into a light fraction and a heavy fraction. The cutting temperature is listed in Table 5. The heavy fraction and the first hydro-treated gas-phase stream obtained in the step (1) are fed into a hydrofining unit 5 that is provided with a first hydrofining unit 51 (a first hydrofining catalyst bed layer) and a second hydrofining unit 52 (a second hydrofining catalyst bed layer). The heavy fraction and the first hydro-treated gas-phase stream obtained in the step (1) are fed through the first hydrofining catalyst bed layer to obtain a first hydro-fined stream, and the first hydro-fined stream and the light fraction are fed through the second hydrofining catalyst bed layer to obtain the resultant hydro-fined stream. The first hydrofining conditions and the second hydrofining conditions are listed in Table 5. The separation and fractionation of the resultant hydro-fined stream are carried out according to the examples 1-3.

Wherein, the hydro-treated hydrogen-rich gas and the hydro-fined hydrogen-rich gas are recycled and used together with make-up hydrogen to provide hydrogen-containing gas (the volume content of hydrogen is about 88-92%) required for the system.

In the Table 5, the FZC series refers to a composite of 10vol% FZC-100, 30vol% FZC-105, and 60vol% FZC-106.

Table 5

	Example 5	Example 6	Example 7
First hydro-treating conditions			
Feedstock	Wax oil 1	Wax oil 1	Wax oil 2

Catalyst	FZC series/FF-24	FZC series/FF-24	FZC series/FF-24
Volume ratio of catalyst	10:90	10:90	15:85
Reaction pressure, MPa	6.0	17.0	12.0
Hydrogen to oil at inlet(v/v)	800:1	1000:1	700:1
Total volumetric space velocity, h ⁻¹	0.8	4.0	2.0
Average reaction temperature, °C	350	385	375
Percent of the first hydro-treated stream A in the first hydro-treated stream, wt%	22	53	38
Volume percent of hydro-treated gas-phase stream in the hydrogen-containing gas at the inlet, %	20	50	35
Second hydro-treating conditions			
Feedstock	First hydro-treated stream B and first hydro-treated liquid-phase stream		
Catalyst	FF-24	FF-24	FF-24
Reaction pressure, MPa	6.0	17.0	12.0
Hydrogen to oil at inlet(v/v)	1000:1	1200:1	1500:1
Volumetric space velocity, h ⁻¹	0.8	4.0	1.6
Average reaction temperature, °C	355	385	370
First hydrofining conditions			
Weight ratio of light catalytic cracking cycle oil to wax oil	0.3:1	1.1:1	0.6:1
Cutting temperature, °C	280	260	270
Catalyst	FHUDS-5	FHUDS-5	FHUDS-5
Reaction pressure, MPa	6.0	17.0	12.0
Hydrogen to oil at inlet(v/v)	1000:1	1200:1	1500:1
Volumetric space velocity, h ⁻¹	1.5	1.6	2.1
Average reaction temperature, °C	370	356	375
Second hydrofining conditions			

Catalyst	FHUDS-5	FHUDS-5	FHUDS-5
Reaction pressure, MPa	6.0	17.0	12.0
Hydrogen to oil at inlet(v/v)	1000:1	1200:1	1500:1
Volumetric space velocity, h ⁻¹	3.3	4.0	4.5
Average reaction temperature, °C	345	340	365

The properties of the products obtained in the examples 5-7 are listed in Table 6.

Table 6

	Example 5	Example 6	Example 7
Hydro-treated naphtha			
Sulfur content, µg/g	60	<0.5	<0.5
Hydro-fined naphtha			
Sulfur content, µg/g	10	<0.5	<0.5
Hydro-treated diesel oil			
Sulfur content, µg/g	400	<10	45
Hydro-fined diesel oil			
Sulfur content, µg/g	45	<10	85
Content of monocyclic aromatic hydrocarbons, wt%	75.3	77.5	85.1
Hydro-treated heavy fraction			
Sulfur content, µg/g	1900	210	450

- 5 It is seen from the results of the examples of the present invention, target products of different specifications can be produced as required with the wax oil hydrogenation method and system provided in the present invention; in addition, the sulfur content in the hydro-treated naphtha, hydro-fined naphtha, hydro-treated diesel oil, hydro-fined diesel oil, and hydro-treated heavy fraction can be decreased effectively, and the content of monocyclic aromatic hydrocarbons in the
- 10 hydro-fined diesel oil can be improved. Thus, the hydro-fined diesel oil can be used as high-quality FCC feedstock, and can improve the content of aromatic hydrocarbons in the FCC gasoline when

they are fed into a FCC unit. It is seen from the result of comparison between the examples 1-3 and the examples 5-7: the preferred embodiment of the present invention is more favorable for reducing the sulfur content in the products and can further improve the content of monocyclic aromatic hydrocarbons in the hydro-fined diesel oil.

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While the present invention is described above in detail in some preferred embodiments with reference to the accompanying drawings, the present invention is not limited to those embodiments. Various simple variations, including combinations of the technical features in any other appropriate way, can be made to the technical scheme of the present invention within the scope of the technical concept of the present invention, but such variations and combinations shall be deemed as disclosed content in the present invention and falling in the protection scope of the present invention.

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Claims

1. A wax oil hydrogenation method, comprising the following steps:
(1)controlling wax oil as feedstock and a hydrogen-containing gas to contact with a first hydro-treating catalyst under first hydro-treating conditions, dividing a first hydro-treated stream obtained through the contact into two parts, i.e., a first hydro-treated stream **A** and a first hydro-treated stream **B**, and performing gas-liquid separation of the first hydro-treated stream **A** to obtain a first hydro-treated gas-phase stream and a first hydro-treated liquid-phase stream;
(2)controlling the first hydro-treated stream **B**, the first hydro-treated liquid-phase stream, and a hydrogen-containing gas to contact with a second hydro-treating catalyst under second hydro-treating conditions, to obtain a resultant hydro-treated stream; and
(3)controlling the first hydro-treated gas-phase stream and light catalytic cracking cycle oil to contact with a hydrofining catalyst to have a hydrofining reaction under hydrofining conditions, to obtain a resultant hydro-fined stream.
2. The method according to claim 1, wherein the initial boiling point of the wax oil is 100-400°C, and the final boiling point of the wax oil is 405-650°C;
preferably, the wax oil is selected from at least one of vacuum gas oil (VGO), coker gas oil (CGO), deasphalted oil (DAO), coal tar, direct coal liquefaction distillate (DCLD), indirect coal liquefaction distillate (ICLD), synthetic oil, and shale oil.
3. The method according to claim 1, wherein the initial boiling point of the light catalytic cracking cycle oil is 100-200°C, and the final boiling point of the light catalytic cracking cycle oil is 320-400°C;
preferably, the weight ratio of the light catalytic cracking cycle oil to the wax oil is 0.1-3:1, more preferably is 0.3-1.1:1.
4. The method according to claim 1, wherein the first hydro-treating catalyst and the second hydro-treating catalyst contain a carrier and an active component respectively and independently, wherein, the active component is selected from at least one of VIB and/or VIII metal elements, and the carrier is alumina and/or silicon-containing alumina;
preferably, based on the total weight of the first hydro-treating catalyst and measured in oxide, the content of the VIB metal element is 10-35wt%, and the content of the VIII metal element is 3-15wt%;

preferably, based on the total weight of the second hydro-treating catalyst and measured in oxide, the content of the VIB metal element is 10-35wt%, and the content of the VIII metal element is 3-15wt%;

preferably, the specific surface area of the first hydro-treating catalyst is 100-650m²/g, and the pore volume of the first hydro-treating catalyst is 0.15-0.6mL/g;

preferably, the specific surface area of the second hydro-treating catalyst is 100-650m²/g, and the pore volume of the second hydro-treating catalyst is 0.15-0.6mL/g.

5. The method according to claim 1, wherein the first hydro-treating conditions and the second hydro-treating conditions respectively and independently include: reaction pressure: 3-19MPa, reaction temperature: 300-450°C, liquid hourly space velocity: 0.2-6h⁻¹, and volume ratio of hydrogen to oil: 100-2,000:1;

preferably, the first hydro-treating conditions and the second hydro-treating conditions respectively and independently include: reaction pressure: 4-17MPa, reaction temperature: 320-420°C, liquid hourly space velocity: 0.4-4h⁻¹, and volume ratio of hydrogen to oil: 400-1,500:1.

6. The method according to any of claims 1-5, wherein the hydro-treated gas-phase stream accounts for 5-95vol% of the hydrogen-containing gas in the step (1), preferably is 10-80vol%.

7. The method according to any of claims 1-5, wherein the first hydro-treated stream **A** accounts for 5-95wt% of the total weight of the first hydro-treated stream **A** and the first hydro-treated stream **B**, preferably is 10-80wt%.

8. The method according to any of claims 1-5, wherein the hydrofining catalyst contains a carrier and an active component, wherein, the active component is selected from at least one of VIB and/or VIII metal elements, and the carrier is alumina and/or silicon-containing alumina;

preferably, based on the total weight of the hydrofining catalyst and measured in oxide, the content of the VIB metal element is 10-35wt%, and the content of the VIII metal element is 3-15wt%;

preferably, the specific surface area of the hydrofining catalyst is 100-650m²/g, and the pore volume of the hydro-treating catalyst is 0.15-0.6mL/g;

preferably, the hydrofining conditions include: reaction pressure: 3-19MPa, reaction temperature: 260-450°C, liquid hourly space velocity: 0.2-6h⁻¹, and volume ratio of hydrogen to

oil: 100-2,000:1, further preferably the reaction temperature is 280-410°C.

9. The method according to any of claims 1-8, wherein the method further comprising: cutting the light catalytic cracking cycle oil to obtain a light fraction and a heavy fraction, wherein, the cutting temperature is 245-300°C; the step (3) comprises: controlling the first hydro-treated gas-phase stream, the heavy fraction, and a hydrogen-containing gas to contact with a first hydrofining catalyst to have a first hydrofining reaction under first hydrofining conditions, to obtain a first hydro-fined stream; then controlling the first hydro-fined stream, the light fraction, and a hydrogen-containing gas to contact with a second hydrofining catalyst to have a second hydrofining reaction under second hydrofining conditions; preferably, the temperature of the second hydrofining reaction is lower than the temperature of the first hydrofining reaction; further preferably, the temperature of the second hydrofining reaction is lower than the temperature of the first hydrofining reaction by 5-20°C.

10. The method according to any of claims 1-9, wherein the step (2) further comprises: treating the resultant hydro-treated stream by separation and fractionation to obtain a hydro-treated hydrogen-rich gas, a hydro-treated gas, a hydro-treated naphtha, a hydro-treated diesel oil, and a hydro-treated heavy fraction; the step (3) further comprises: treating the resultant hydro-fined stream by separation and fractionation to obtain a hydro-fined hydrogen-rich gas, a hydro-fined gas, a hydro-fined naphtha, and a hydro-fined diesel oil; preferably, the separation in the step (2) comprises high-pressure separation and low-pressure separation, the resultant hydro-treated stream is treated by high-pressure separation to obtain the hydro-treated hydrogen-rich gas and a hydro-treated high-pressure separated liquid-phase stream, and then the hydro-treated high-pressure separated liquid-phase stream is treated by low-pressure separation to obtain the hydro-treated gas and a hydro-treated liquid-phase stream, and the hydro-treated liquid-phase stream is treated by fractionation to obtain the hydro-treated naphtha, the hydro-treated diesel oil, and the hydro-treated heavy fraction; preferably, the separation in the step (3) comprises high-pressure separation and low-pressure separation, the resultant hydro-fined stream is treated by high-pressure separation to obtain the hydro-fined hydrogen-rich gas and a hydro-fined high-pressure separated liquid-phase stream, and then the hydro-fined high-pressure separated liquid-phase stream is treated by low-pressure separation to obtain the hydro-fined gas and a hydro-fined liquid-phase stream, and the hydro-fined liquid-phase stream is treated by fractionation to obtain the hydro-fined naphtha and the hydro-fined diesel oil;

preferably, the method further comprises: recycling the hydro-treated hydrogen-rich gas and the hydro-fined hydrogen-rich gas to provide required hydrogen-containing gas.

11. The method according to any of claim 1-9, wherein the method further comprising: mixing the resultant hydro-treated stream and the resultant hydro-fined stream to obtain a mixture flow, and then treating the mixture flow by separation and fractionation;

preferably, the mixture flow is treated by high-pressure separation to obtain a mixed hydrogen-rich gas and a mixed high-pressure separated liquid-phase stream, and then the mixed high-pressure separated liquid-phase stream is treated by low-pressure separation to obtain a mixed gas and a mixed liquid-phase stream, and the mixed liquid-phase stream is treated by fractionation to obtain a mixed naphtha, a mixed diesel oil, and a mixed heavy fraction;

preferably, the method further comprises: recycling the mixed hydrogen-rich gas to provide required hydrogen-containing gas.

12. A wax oil hydrogenation system, comprising:

a first hydro-treating unit (1);

a gas-liquid separator (2) configured to perform gas-liquid separation for a part of first hydro-treated stream obtained in the first hydro-treating unit (1) to obtain a first hydro-treated gas-phase stream and a first hydro-treated liquid-phase stream;

a second hydro-treating unit (3) configured to perform second hydro-treatment for the remaining part of the first hydro-treated stream and the first hydro-treated liquid-phase stream in it to obtain a resultant hydro-treated stream;

a light catalytic cracking cycle oil supply unit (4) configured to supply light catalytic cracking cycle oil; and

a hydrofining unit (5) configured to perform hydrofining for the light catalytic cracking cycle oil supplied by the light catalytic cracking cycle oil supply unit (4) and the hydro-treated gas-phase stream in it to obtain a resultant hydro-fined stream.

13. The system according to claim 12, wherein the gas-liquid separator (2) comprises a reactant inlet, a liquid phase conduit, and a gas phase conduit; the reactant inlet of the gas-liquid separator (2) communicates with the outlet of the first hydro-treating unit (1), the first hydro-treated liquid-phase stream is led into the second hydro-treating unit (3) through the liquid phase conduit, and the first hydro-treated gas-phase stream is led into the hydrofining unit (5) through the gas phase conduit.

14. The system according to claim 12 or 13, wherein the system further comprising:

a hydro-treating separation unit comprising a hydro-treating high-pressure separator (61) and a hydro-treating low-pressure separator (62) that are connected in series, wherein, the outlet of the second hydro-treating unit (3) communicates with the inlet of the hydro-treating high-pressure separator (61) through a pipeline; the resultant hydro-treated stream is separated at a high pressure in the hydro-treating high-pressure separator (61) to obtain a hydro-treated hydrogen-rich gas and a hydro-treated high-pressure separated liquid-phase stream, and then the hydro-treated high-pressure separated liquid-phase stream is separated at a low pressure in the hydro-treating low-pressure separator (62) to obtain a hydro-treated gas and a hydro-treated liquid-phase stream;

a hydro-treating fractionation tower (7), wherein the inlet of the hydro-treating fractionation tower (7) communicates with the outlet of the hydro-treating low-pressure separator (62) through a pipeline, the hydro-treated liquid-phase stream is fractionated in the hydro-treating fractionation tower (7) to obtain a hydro-treated naphtha, a hydro-treated diesel oil, and a hydro-treated heavy fraction;

a hydrofining separation unit comprising a hydrofining high-pressure separator (81) and a hydrofining low-pressure separator (82) that are connected in series, wherein, the outlet of the hydrofining unit (5) communicates with the inlet of the hydrofining high-pressure separator (81) through a pipeline; the resultant hydro-fined stream is separated at a high pressure in the hydrofining high-pressure separator (81) to obtain a hydro-fined hydrogen-rich gas and a hydro-fined high-pressure separated liquid-phase stream, and then the hydro-fined high-pressure separated liquid-phase stream is separated at a low pressure in the hydrofining low-pressure separator (82) to obtain a hydro-fined gas and a hydro-fined liquid-phase stream; and

a hydrofining fractionation tower (9), wherein the inlet of the hydrofining fractionation tower (9) communicates with the outlet of the hydrofining low-pressure separator (82) through a pipeline, the hydro-fined liquid-phase stream is fractionated in the hydrofining fractionation tower (9) to obtain a hydro-fined naphtha and a hydro-fined diesel oil.

15. The system according to claim 14, wherein the gas phase outlet of the hydro-treating high-pressure separator (61) and the gas phase outlet of the hydrofining high-pressure separator (81) communicate with the inlet of the first hydro-treating unit (1) and/or the inlet of the second hydro-treating unit (3) respectively and independently, to recycle the hydro-treated hydrogen-rich gas and the hydro-fined hydrogen-rich gas so as to provide hydrogen required for

the system.

16. The system according to claim 12 or 13, wherein the system further comprising:

a mixing separation unit and a mixing fractionation tower (11), wherein, the mixing separation unit comprises a mixing high-pressure separator (101) and a mixing low-pressure separator (102) that are connected in series, and the outlet of the mixing low-pressure separator (102) communicates with the inlet of the mixing fractionation tower (11);

the outlet of the second hydro-treating unit (3) and the outlet of the hydrofining unit (5) communicate with the inlet of the mixing high-pressure separator (101); the resultant hydro-treated stream and the resultant hydro-fined stream are mixed and then separated at a high pressure in the mixing high-pressure separator (101) to obtain a mixed hydrogen-rich gas and a mixed high-pressure separated liquid-phase stream;

the mixed high-pressure separated liquid-phase stream is separated at a low pressure in the mixing low-pressure separator (102) to obtain a mixed gas and a mixed liquid-phase stream;

the mixed liquid-phase stream is fractionated in the mixing fractionation tower (11) to obtain a mixed naphtha, a mixed diesel oil, and a mixed heavy fraction;

preferably, the gas-phase outlet of the mixing high-pressure separator (101) communicates with the inlet of the first hydro-treating unit (1) and/or the inlet of the second hydro-treating unit (3) to recycle the mixed hydrogen-rich gas so as to provide hydrogen required for the system.

17. The system according to any of claims 12-16, wherein the hydrofining unit (5) comprises a first hydrofining unit (51) and a second hydrofining unit (52) that are arranged in series;

the system further comprises: a light catalytic cracking cycle oil fractionation tower (12) arranged between the first hydrofining unit (51) and the light catalytic cracking cycle oil supply unit (4) to cut the light catalytic cracking cycle oil supplied by the light catalytic cracking cycle oil supply unit (4) into a light fraction and a heavy fraction;

the heavy fraction and the first hydro-treated gas-phase stream are hydro-fined in the first hydrofining unit (51) to obtain a first hydro-fined stream; the first hydro-fined stream and the light fraction are hydro-fined in the second hydrofining unit (52) to obtain the resultant hydro-fined stream.