DESCRIPTION

Title of Invention: HYDROGEN PRODUCTION METHOD AND HYDROCARBON MIXTURE PROCESSING METHOD

Technical Field

[0001] The present invention relates to a method for producing hydrogen and a method for treating a hydrocarbon mixture.

Background Art

[0002] In recent years, the development and practical application of hydrogen energy utilization technologies such as fuel cell vehicles have been advancing, and the development of technologies for purifying, storing, and transporting hydrogen has been vigorously pursued. For example, Patent Literature 1 examines a hydrogen purification method in which a fossil fuel such as naphtha is hydrogenated in the presence of a hydrogenation catalyst to obtain a hydrogenated aromatic compound (organic hydride), and then dehydrogenation of the hydrogenated aromatic compound is carried out in the presence of a dehydrogenation catalyst, and the hydrogen obtained by this dehydrogenation is recovered.

Citation List

Patent Literature

[0003] [Patent Literature 1] Japanese Unexamined Patent Publication No. 2006-052110

Summary of Invention

Technical Problem

[0004] Conventionally, hydrogen carriers such as ammonia, which is a

form of hydrogen derivative, and inorganic and organic hydrides have been studied as media for transporting energy from areas suitable for supplying clean energy to areas demanding clean energy. When these hydrogen carriers are used, not only is there an energy loss during the production and transportation of the relevant substances and hydrogen production, but also deterioration and loss of the hydrogen carriers occur in a series of processes, resulting in high costs and limited actual environmental value. In addition, there is the reality that all facilities involved in this series of processes need to be newly established, requiring enormous investment, and thus social implementation has not progressed.

[0005] In view of the above circumstances, one aspect of the present invention aims to provide a novel method for producing hydrogen in a method for producing hydrogen that includes a step of transporting a hydrogen carrier. Another aspect of the present invention aims to provide a method for producing hydrogen that utilizes existing facilities, reduces the problems of deterioration and loss of the hydrogen carrier, and has excellent energy efficiency, in a method for producing hydrogen that includes a step of transporting a hydrogen carrier.

Solution to Problem

[0006] One aspect of the present invention includes, for example, the following [1] to [26].

[1] A method for producing hydrogen, the method including:

a hydrogenation step of performing hydrogenation and a treatment including at least one selected from the group consisting of desulfurization treatment, denitrogenation treatment, demetallization

treatment, and hydrocracking on a mixture containing an aromatic compound and an unsaturated hydrocarbon compound in an environment exceeding 250°C, to obtain a hydrogenated hydrocarbon compound;

a transportation step of transporting the hydrogenated hydrocarbon compound from a first location to a second location; and

a dehydrogenation step of recovering hydrogen from the transported hydrogenated hydrocarbon compound.

[2] The method for producing hydrogen according to [1], wherein the hydrogenation step includes:

separating the mixture so that a proportion of the aromatic compound increases;

hydrogenating the aromatic compound; and

mixing the hydrogenated aromatic compound with a remainder of the mixture from which the aromatic compound has been separated.

[3] The method for producing hydrogen according to [1] or [2], wherein the hydrogenation is performed using clean hydrogen.

[4] The method for producing hydrogen according to any one of [1] to [3], the method further including at least one step selected from the group consisting of:

Step A of electrolyzing water to obtain hydrogen;

Step B including steam-reforming methane to generate hydrogen and carbon dioxide, and separating the generated carbon dioxide and storing it underground; and

Step C of thermally decomposing a gas containing methane to obtain hydrogen,

before the hydrogenation step,

wherein the hydrogenation step is a step of performing hydrogenation using the hydrogen obtained in any one of Steps A to C.

[5] The method for producing hydrogen according to any one of [1] to [4], wherein the unsaturated hydrocarbon compound is an olefin.

[6] The method for producing hydrogen according to any one of [1] to [5], wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having a 90 volume% distillation temperature of ASTM D1160 of 360°C or higher and an RVP of 13 psi or less, in which a total mass concentration of aromatic compounds in compounds having an NBP of 300°C or lower contained in the hydrocarbon mixture is 1/10 or less of a total mass concentration of cyclic alkanes.

[7] The method for producing hydrogen according to any one of [1] to [5], wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having an End Boiling Point of ASTM D86 of 230°C or lower, in which a total mass concentration of benzene, toluene, xylene, and ethylbenzene is 1/10 or less of a total mass concentration of cyclohexane, methylcyclohexane, dimethylcyclohexane, and ethylcyclohexane in the hydrocarbon mixture, and a total mass concentration of paraffin compounds including hexane and heptane is 1/10 or more of a total mass concentration of the hydrogenated hydrocarbon mixture.

[8] The method for producing hydrogen according to any one of [1] to [5], wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having a 5 volume% distillation temperature of ASTM D1160 of 300°C or higher, in which a total mass concentration of

aromatic compounds contained in the hydrocarbon mixture is 1/2 or less of a total mass concentration of cyclic alkanes.

[9] The method for producing hydrogen according to any one of [1] to [8], wherein the dehydrogenation step is a step performed using at least one device selected from the group consisting of a catalytic reforming device, an ethylene production device, a thermal decomposition device, and a catalytic decomposition device.

[10] The method for producing hydrogen according to any one of [1] to [9], wherein the dehydrogenation step is a step performed using at least one device selected from the group consisting of an ethylene production device, a thermal decomposition device, and a catalytic decomposition device, and

the method further includes a separation step of purifying the hydrogen by at least one separation treatment selected from the group consisting of membrane separation, adsorption separation, and cryogenic separation, after the dehydrogenation step.

[11] The method for producing hydrogen according to any one of [1] to [10], wherein the dehydrogenation step is a step of recovering hydrogen from the transported hydrogenated hydrocarbon compound and other hydrogenated hydrocarbon compounds other than the transported hydrogenated hydrocarbon compound, and

the method further includes:

a calculation step of calculating a mass fraction of hydrogen generated from the transported hydrogenated hydrocarbon compound among the recovered hydrogen; and

a step of dividing the recovered hydrogen based on the mass

fraction, after the dehydrogenation step.

[12] The method for producing hydrogen according to any one of [1] to [11], wherein the dehydrogenation step is a step of producing a mixture containing at least one selected from the group consisting of ethylene, propylene, benzene, toluene, xylene, and solid carbon, together with the hydrogen.

[13] A method for treating a hydrocarbon mixture, the method including:

a hydrogenation step of performing hydrogenation and a treatment including at least one selected from the group consisting of desulfurization treatment, denitrogenation treatment, demetallization treatment, and hydrocracking on a mixture containing an aromatic compound and an unsaturated hydrocarbon compound in an environment exceeding 250°C, to obtain a hydrogenated hydrocarbon compound; and

a transportation step of transporting the hydrogenated hydrocarbon compound from a first location to a second location.

[14] The method for treating a hydrocarbon mixture according to [13], wherein the hydrogenation step includes:

separating the mixture so that a proportion of the aromatic compound increases;

hydrogenating the aromatic compound; and

mixing the hydrogenated aromatic compound with a remainder of the mixture from which the aromatic compound has been separated.

[15] The method for treating a hydrocarbon mixture according to [13] or [14], wherein the hydrogenation is performed using clean hydrogen.

[16] The method for treating a hydrocarbon mixture according to any one of [13] to [15], the method further including at least one step selected from the group consisting of:

Step A of electrolyzing water to obtain hydrogen;

Step B including steam-reforming methane to generate hydrogen and carbon dioxide, and separating the generated carbon dioxide and storing it underground; and

Step C of thermally decomposing a gas containing methane to obtain hydrogen,

before the hydrogenation step,

wherein the hydrogenation step is a step of performing hydrogenation using the hydrogen obtained in any one of Steps A to C.

[17] The method for treating a hydrocarbon mixture according to any one of [13] to [16], wherein the unsaturated hydrocarbon compound is an olefin.

[18] The method for treating a hydrocarbon mixture according to any one of [13] to [17], wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having a 90 volume% distillation temperature of ASTM D1160 of 360°C or higher and an RVP of 13 psi or less, in which a total mass concentration of aromatic compounds in compounds having an NBP of 300°C or lower contained in the hydrocarbon mixture is 1/10 or less of a total mass concentration of cyclic alkanes.

[19] The method for treating a hydrocarbon mixture according to any one of [13] to [17], wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having an End Boiling Point of ASTM D86 of 230°C or lower, in which a total mass concentration of benzene, toluene,

xylene, and ethylbenzene is 1/10 or less of a total mass concentration of cyclohexane, methylcyclohexane, dimethylcyclohexane, and ethylcyclohexane in the hydrocarbon mixture, and a concentration of paraffin compounds including hexane and heptane is 1/10 or more of a total mass concentration of the hydrogenated hydrocarbon mixture.

[20] The method for treating a hydrocarbon mixture according to any one of [13] to [17], wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having a 5 volume% distillation temperature of ASTM D1160 of 300°C or higher, in which a total mass concentration of aromatic compounds contained in the hydrocarbon mixture is 1/2 or less of a total mass concentration of cyclic alkanes.

[21] A method for producing hydrogen, the method including:

a transportation step of transporting a hydrogenated hydrocarbon compound from a first location to a second location; and

a dehydrogenation step of recovering hydrogen from the transported hydrogenated hydrocarbon compound.

[22] The method for producing hydrogen according to [21], wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having a 90 volume% distillation temperature of ASTM D1160 of 360°C or higher and an RVP of 13 psi or less, in which a total mass concentration of aromatic compounds in compounds having an NBP of 300°C or lower contained in the hydrocarbon mixture is 1/10 or less of a total mass concentration of cyclic alkanes.

[23] The method for producing hydrogen according to [21], wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having an End Boiling Point of ASTM D86 of 230°C or lower, in which

a total mass concentration of benzene, toluene, xylene, and ethylbenzene is 1/10 or less of a total mass concentration of cyclohexane, methylcyclohexane, dimethylcyclohexane, and ethylcyclohexane in the hydrocarbon mixture, and a total mass concentration of paraffin compounds including hexane and heptane is 1/10 or more of a total mass concentration of the hydrogenated hydrocarbon mixture.

[24] The method for producing hydrogen according to [21], wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having a 5 volume% distillation temperature of ASTM D1160 of 300°C or higher, in which a total mass concentration of aromatic compounds contained in the hydrocarbon mixture is 1/2 or less of a total mass concentration of cyclic alkanes.

[25] The method for producing hydrogen according to any one of [21] to [24], wherein the dehydrogenation step is a step performed using at least one device selected from the group consisting of a catalytic reforming device, an ethylene production device, a thermal decomposition device, and a catalytic decomposition device.

[26] The method for producing hydrogen according to any one of [21] to [25], wherein the dehydrogenation step is a step performed using at least one device selected from the group consisting of an ethylene production device, a thermal decomposition device, and a catalytic decomposition device, and

the method further includes a separation step of purifying the hydrogen by at least one separation treatment selected from the group consisting of membrane separation, adsorption separation, and cryogenic separation, after the dehydrogenation step.

[27] The method for producing hydrogen according to any one of [21] to [26], wherein the dehydrogenation step is a step of recovering hydrogen from the transported hydrogenated hydrocarbon compound and other hydrogenated hydrocarbon compounds other than the transported hydrogenated hydrocarbon compound, and

the method further includes:

a calculation step of calculating a mass fraction of hydrogen generated from the transported hydrogenated hydrocarbon compound among the recovered hydrogen; and

a step of dividing the recovered hydrogen based on the mass fraction, after the dehydrogenation step.

[28] The method for producing hydrogen according to any one of [21] to [27], wherein the dehydrogenation step is a step of producing a hydrocarbon mixture containing at least one selected from the group consisting of ethylene, propylene, benzene, toluene, xylene, and solid carbon, together with the hydrogen.

Advantageous Effects of Invention

[0007] According to one aspect of the present invention, a novel method for producing hydrogen can be provided in a method for producing hydrogen that includes a step of transporting a hydrogen carrier. Further, according to another aspect of the present invention, a method for producing hydrogen that utilizes existing facilities, reduces the problems of deterioration and loss of the hydrogen carrier, and has excellent energy efficiency can be provided in a method for producing hydrogen that includes a step of transporting a hydrogen carrier.

Brief Description of Drawings

[0008] FIG. 1 is a configuration diagram showing a hydrogen production facility according to an embodiment of the present invention.

Description of Embodiments

[0009] Hereinafter, embodiments of the present invention will be described in detail with reference to the drawings. In the following description, the same or corresponding parts are denoted by the same reference signs, and overlapping descriptions are omitted.

[0010] [Hydrogen Production Facility]

FIG. 1 is a configuration diagram showing a hydrogen production facility according to an embodiment of the present invention. The hydrogen production facility 100 shown in FIG. 1 is divided into a first location side and a second location side, and has a hydrogenation facility 10 on the first location side and a dehydrogenation facility 20 on the second location side.

[0011] The hydrogenation facility 10 is present on the first location side. The hydrogenation facility 10 includes a treatment device 11, a hydrogenation device 12, and a hydrogen generation device 13.

[0012] A hydrocarbon mixture is transferred to the treatment device 11 through a transfer pipe L11. Examples of the hydrocarbon mixture include a crude oil and a naphtha and the like. The treatment device 11 adjusts the properties of a treated oil supplied to the hydrogenation device 12 through a transfer pipe L12. The treatment device 11 may be a distillation device or a decomposition reaction facility, or a combination thereof.

[0013] When the treatment device 11 is a distillation device, the

distillation may be performed, for example, under conditions where the top pressure of a distillation column is 1 to 1500 kPa and the temperature at the bottom is 150 to 400°C. In addition, the treatment device 11 may be a combination of a plurality of distillation columns.

[0014] When the treatment device 11 is a decomposition reaction device, the decomposition reaction may be performed, for example, under conditions of a thermal decomposition reaction using heat of 400°C or higher, or a reaction using a catalyst or a solid equivalent thereto. The treatment device 11 may be a combination of a plurality of reaction devices, and may include a distillation column at a stage preceding or following the reaction device, or both.

[0015] The treated oil is a mixture containing an aromatic compound, an unsaturated hydrocarbon compound, or both. Examples of the aromatic compound include a benzene, a toluene, a xylene, a naphthalene, a phenanthrene, and an anthracene and the like. Examples of the unsaturated hydrocarbon compound include a hexene, a heptene, and an octene and the like.

[0016] Examples of the treated oil include a naphtha (gasoline feedstock) containing hydrocarbons having 5 to 12 carbon atoms produced using a distillation device, a kerosene containing hydrocarbons having 10 to 12 carbon atoms, a diesel (gas oil) containing hydrocarbons having 12 to 20 carbon atoms, a vacuum gas oil, a residue (heavy oil) having 20 or more carbon atoms, and a mixture of any combination thereof. Treated oils produced by decomposition reactions are called cracked naphtha, cracked kerosene, cracked diesel, cracked vacuum gas oil, and cracked residue, respectively, and a mixture of any combination

thereof may also be used.

[0017] The treated oil may be a product distilled through a separation operation to ensure maximum hydrogen saturation in the hydrogenation device 12. For example, when the treated oil is a diesel or a vacuum gas oil, the treated oil may be separated so that the proportion of aromatic compounds (for example, polycyclic aromatic compounds) increases. By increasing the proportion of aromatic compounds, it becomes easier to achieve maximum hydrogen saturation in the hydrogenation device 12, the efficiency of the hydrogenation treatment is improved, and the throughput can be minimized. The separation of aromatic compounds from the treated oil may be performed by a distillation device.

[0018] In addition to aromatic compounds, from the viewpoint of efficiently performing hydrogenation, compounds having a boiling point of 100°C or higher may also be separated. For example, when the treated oil is a naphtha, the treated oil may be separated so that the proportion of a hydrocarbon mixture having 6 to 10 carbon atoms increases.

[0019] Naphtha contains, for example, chain alkanes such as pentane, hexane, and octane; chain alkenes (olefins) such as ethylene, propylene, and butene; cyclic alkanes such as cyclohexane; and aromatic hydrocarbons such as benzene and toluene. The boiling point range of naphtha may be, for example, 30 to 200°C.

[0020] Kerosene contains, for example, chain alkanes such as decane, dodecane, and tetradecane; cyclic alkanes such as cyclododecane; and aromatic hydrocarbons such as naphthalene and the like. The boiling point range of kerosene may be, for example, 150 to 275°C.

[0021] Diesel contains, for example, chain alkanes such as dodecane, hexadecane, and octadecane; and aromatic hydrocarbons such as phenanthrene and anthracene and the like. The boiling point range of diesel may be, for example, 250 to 350°C.

[0022] Residue contains, for example, chain alkanes such as eicosane, triacontane, and pentacontane; and aromatic hydrocarbons such as asphaltene and the like. The boiling point of residue may be, for example, 350°C or higher.

[0023] Vacuum gas oil contains hydrocarbons having 20 to 40 carbon atoms. The boiling point of vacuum gas oil may be 350 to 550°C. Vacuum residue contains hydrocarbons having 40 or more carbon atoms. The boiling point of vacuum residue may be 550°C or higher.

[0024] Vacuum gas oil contains, for example, chain alkanes such as eicosane, docosane, triacontane, isoeicosane, and isodocosane; cyclic alkanes such as cyclohexadecane and cyclooctadecane; and aromatic hydrocarbons such as phenanthrene, anthracene, and benzopyrene and the like.

[0025] The treatment device 11 is connected to the transfer pipe L12 and a transfer pipe L13. The transfer pipe L12 transfers the treated oil, and the transfer pipe L13 transfers other fractions.

[0026] The treated oil is transferred to the hydrogenation device 12 through the transfer pipe L12. The hydrogenation device 12 is a device that hydrogenates the treated oil (a mixture containing an aromatic compound and an unsaturated hydrocarbon compound) transferred through the transfer pipe L12 using hydrogen transferred through a transfer pipe L14, to obtain a hydrogenated hydrocarbon compound (for

example, hydrogenated naphtha). The hydrogen transferred through the transfer pipe L14 is generated by the hydrogen generation device 13. The hydrogenated hydrocarbon compound is transported to the second location by a transportation means T1, and by-products and impurities in the hydrogenation device 12 are discharged through a transfer pipe L15. That is, the hydrogenated hydrocarbon compound transported from the first location to the second location by the transportation means T1 is a hydrogen carrier.

[0027] The hydrogenation of the treated oil is performed in an environment exceeding 250°C. Performing the hydrogenation at a temperature exceeding 250°C promotes the hydrogenation reaction and can completely remove impurities (such as nitrogen and sulfur) that are not permitted to be contained in products in subsequent facilities. The hydrogenation of the treated oil may be performed under conditions of a temperature of 250 to 400°C, and may be performed under conditions of a pressure of 2 to 20 MPa. The hydrogenation of the treated oil may be performed in the presence of a catalyst, and the catalyst may be one in which a metal such as nickel is supported on a simple substance such as alumina.

[0028] The hydrogen used in the hydrogenation of the treated oil may be clean hydrogen. Clean hydrogen is hydrogen produced by an environmentally conscious method, and means hydrogen in which the amount of harmful substances such as greenhouse gases released into the atmosphere during the production process is reduced. The carbon intensity in the production of this clean hydrogen may be, for example, 3.0 kg-CO_2/kg-H_2 or less.

[0029] The clean hydrogen may be green hydrogen generated by electrolyzing water, may be blue hydrogen obtained by producing a mixture of hydrogen and carbon dioxide by steam reforming (steam methane reforming) or the like, separating the carbon dioxide from the mixture, and storing it underground, or may be turquoise hydrogen generated by thermally decomposing a gas containing a hydrocarbon such as natural gas (for example, methane). The hydrogen used in the hydrogenation of the treated oil may be a combination of these types of clean hydrogen. A storage battery may be used to respond to power load fluctuations during the production of these types of hydrogen. That is, the hydrogen generation device 13 may be a device that generates green hydrogen produced by electrolyzing water, may be a device that generates blue hydrogen obtained by producing a mixture of hydrogen and carbon dioxide by steam reforming (steam methane reforming) or the like, separating the carbon dioxide from the mixture, and storing it underground, or may be a device that generates turquoise hydrogen generated by thermally decomposing a gas containing a hydrocarbon such as natural gas (for example, methane). The hydrogen used in the hydrogenation of the treated oil may be a combination of these types of clean hydrogen. A storage battery may be used to respond to power load fluctuations during the production of these types of hydrogen. In addition, the electric power used during the production of these types of hydrogen may be electric power with a low carbon intensity (for example, electric power derived from renewable energy).

[0030] Performing the hydrogenation of the treated oil using clean hydrogen allows the by-product hydrogen generated when a

dehydrogenation reaction is performed for the purpose of producing products at the second location to also be regarded as clean hydrogen, and thus it becomes a high value-added product. This series of processes is substantially equivalent to the process of transporting crude oil and its derivatives from the first location to the second location and treating them at the second location for the purpose of producing fuels, chemical raw materials, and the like from the transported crude oil and its derivatives, and therefore the energy consumed for the purpose of transporting hydrogen is energy that is also required in the related art processes, and substantially no additional cost is incurred. The hydrogen used in the hydrogenation of the treated oil may include hydrogen produced before transportation by a method with a carbon intensity of 3.0 kg-CO_2/kg-H_2 or less.

[0031] The hydrogenated hydrocarbon compound contains chain alkanes such as hexane, octane, decane, dodecane, hexadecane, and octadecane; cyclic alkanes such as cyclohexane and cyclododecane; and the like. Since the hydrogenated hydrocarbon compound is a compound equivalent to hydrocarbon compounds generally distributed in the market, compared to the case of producing an organic hydride, there is no need to newly establish facilities for producing a hydrogen carrier, and it is possible to utilize existing facilities. It should be noted that only existing facilities may be used to produce the hydrogen carrier, or new facilities may be used as needed.

[0032] When the treated oil supplied through the transfer pipe L12 contains a residue derived from crude oil, the hydrogenated hydrocarbon compound obtained in the hydrogenation device 12 may be a

hydrocarbon mixture having a 90 volume% distillation temperature of ASTM D1160 of 360°C or higher and an RVP of 13 psi or less, and a total mass concentration of aromatic compounds in compounds having an NBP of 300°C or lower contained in the hydrocarbon mixture may be 1/10 or less of a total mass concentration of cyclic alkanes. In addition, by treating such a hydrogenated hydrocarbon compound in the hydrogenation facility 10, the amount of hydrogen required by the hydrogen utilization device 22 decreases, and the amount of hydrogen supplied from the dehydrogenation device 21 and the hydrogen generation device 23 can be reduced. For example, when the hydrogen utilization device 22 is a hydrodesulfurization device, since the supplied oil contains very small amounts of unsaturated compounds, sulfur, and other impurities, the amount of hydrogen required to meet the specifications of the product distilled from the hydrogen utilization device 22 can be reduced, and the severity of operation of the device can also be reduced. As a result, not only can more clean hydrogen generated from the dehydrogenation device 21 (hydrogen discharged through the transfer pipe L21) be supplied outside the system, but also the carbon intensity of the product obtained from the dehydrogenation device 21 (the product discharged through the transfer pipe L22) can be reduced.

[0033] When the treated oil supplied through the transfer pipe L12 is a naphtha or a cracked naphtha, the hydrogenated hydrocarbon compound obtained in the hydrogenation device 12 may be a hydrocarbon mixture having an End Boiling Point of ASTM D86 of 230°C or lower, in which a total mass concentration of benzene, toluene, xylene, and ethylbenzene

in the hydrocarbon mixture is 1/10 or less of a total mass concentration of cyclohexane, methylcyclohexane, dimethylcyclohexane, and ethylcyclohexane, and a total mass concentration of paraffin compounds including hexane and heptane is 1/10 or more of a total mass concentration of the hydrogenated hydrocarbon mixture. In addition, by treating such a hydrogenated hydrocarbon compound in the hydrogenation facility 10, the amount of hydrogen required by the hydrogen utilization device 22 decreases, and the amount of hydrogen supplied from the dehydrogenation device 21 and the hydrogen generation device 23 can be reduced. For example, when the hydrogen utilization device 22 is a hydrodesulfurization device, since the supplied oil contains very small amounts of unsaturated compounds, sulfur, and other impurities, the amount of hydrogen required to meet the specifications of the product distilled from the hydrogen utilization device 22 can be reduced, and the severity of operation of the device can also be reduced. As a result, not only can more clean hydrogen generated from the dehydrogenation device 21 (hydrogen discharged through the transfer pipe L21) be supplied outside the system, but also the carbon intensity of the product obtained from the dehydrogenation device 21 (the product discharged through the transfer pipe L22) can be reduced.

[0034] When the treated oil supplied through the transfer pipe L12 is a vacuum gas oil or a cracked gas oil equivalent thereto, the hydrogenated hydrocarbon compound obtained in the hydrogenation device 12 may be a hydrocarbon mixture having a 5 volume% distillation temperature of ASTM D1160 of 300°C or higher, in which a total mass concentration of

aromatic compounds contained in the hydrocarbon mixture is 1/2 or less of a total mass concentration of cyclic alkanes. In addition, by treating such a hydrogenated hydrocarbon compound in the hydrogenation facility 10, the amount of hydrogen required by the hydrogen utilization device 22 decreases, and the amount of hydrogen supplied from the dehydrogenation device 21 and the hydrogen generation device 23 can be reduced. For example, when the hydrogen utilization device 22 is a hydrodesulfurization device, since the supplied oil contains very small amounts of unsaturated compounds, sulfur, and other impurities, the amount of hydrogen required to meet the specifications of the products distilled from the hydrogen utilization device 22 can be reduced, and the severity of operation of the device can also be reduced. As a result, not only can more clean hydrogen generated from the dehydrogenation device 21 (hydrogen discharged through the transfer pipe L21) be supplied outside the system, but also the carbon intensity of the product obtained from the dehydrogenation device 21 (the product discharged through the transfer pipe L22) can be reduced.

[0035] In the hydrogenation device 12, the treated oil may be subjected to treatments such as desulfurization treatment, denitrogenation treatment, and demetallization treatment. By performing the desulfurization treatment, denitrogenation treatment, and demetallization treatment at the first location, the amount of clean hydrogen obtained at the second location can be increased, the energy consumed when producing products at the second location can be minimized, and the overall energy efficiency can be maximized.

[0036] In the desulfurization treatment, sulfur compounds (for example,

a thiophene and a benzothiophene) are removed from the treated oil. By performing the removal of sulfur compounds from the treated oil at the first location, the amount of clean hydrogen obtained at the second location can be increased and energy efficiency can be maximized. The desulfurization treatment is performed, for example, under conditions of a temperature of 300 to 400°C and a pressure of 3 to 10 MPa. In the desulfurization treatment, sulfur compounds are converted to hydrogen sulfide using a cobalt-molybdenum catalyst or a nickel-molybdenum catalyst. The hydrogen sulfide generated in the desulfurization treatment may be removed by, for example, absorption into an amine.

[0037] In the denitrogenation treatment, nitrogen compounds (for example, a pyridine and a quinoline) are removed from the treated oil. By performing the removal of nitrogen compounds from the treated oil at the first location, the amount of clean hydrogen obtained at the second location can be increased and energy efficiency can be maximized. The denitrogenation treatment is performed, for example, under conditions of a temperature of 300 to 450°C and a pressure of 3 to 10 MPa. In the denitrogenation treatment, nitrogen compounds are converted to ammonia using a cobalt-molybdenum catalyst or a nickel-molybdenum catalyst. The ammonia generated in the denitrogenation treatment may be removed by, for example, absorption into water.

[0038] In the demetallization treatment, metal compounds are removed from the treated oil. By performing the removal of metal compounds from the treated oil at the first location, the amount of clean hydrogen obtained at the second location can be increased and energy efficiency can be maximized. The demetallization treatment is performed, for

example, under conditions of a temperature of 350 to 450°C and a pressure of 5 to 15 MPa. In the demetallization treatment, for example, a cobalt-molybdenum catalyst is used to decompose the metal compounds, which are then removed by adsorption.

[0039] In the hydrogenation device 12, the treated oil may be brought into contact with high-temperature and high-pressure hydrogen gas and subjected to hydrocracking. By hydrocracking, C-C bonds are cleaved, and low-molecular-weight hydrocarbons can be produced. Hydrocracking may be performed simultaneously with the hydrogenation of vacuum gas oil.

[0040] Hydrocracking is performed under conditions of a temperature of 350 to 450°C and a pressure of 7 to 20 MPa. Hydrocracking may be performed using, for example, a nickel-molybdenum catalyst or a cobalt-molybdenum catalyst.

[0041] The process up to hydrogenation performed at the first location can be carried out using existing facilities in a petroleum plant. Therefore, the hydrogenation facility 10 may be an existing facility, or may be partially or entirely a new facility.

[0042] The hydrogenated hydrocarbon compound produced in the hydrogenation device 12 is transported from the first location to the second location by the transportation means T1. The hydrogenated hydrocarbon compound produced in the hydrogenation device 12 may be temporarily stored in a storage container before and/or after being transported from the first location to the second location. Examples of the transportation means T1 include a ship, a diesel locomotive, a railway, and a truck and the like. The transportation of the hydrogenated

hydrocarbon compound may be performed at normal temperature and normal pressure, at normal temperature and elevated pressure, at low temperature and normal pressure, or at low temperature and elevated pressure. The first location may be, for example, a clean hydrogen production site. The second location may be a hydrogen consumption site, or may be a site where valuable products generated from the hydrogenated hydrocarbon compound are used and consumed. The first location may be a region, a country, or the like where the production cost of clean hydrogen is lower than that of the second location. The second location may be a region, a country, or the like where the demand for clean hydrogen is high and where the consumption of petroleum and petrochemical products generated from the hydrogenated hydrocarbon compound is greater than that of the first location, or where petroleum and petrochemical production facilities are well-established.

[0043] The hydrogenated hydrocarbon compound transported by the transportation means T1 is transported to the dehydrogenation facility 20 at the second location. The dehydrogenation facility 20 includes a dehydrogenation device 21.

[0044] The dehydrogenation device 21 is a device that produces and recovers hydrogen from the hydrogenated hydrocarbon compound. The hydrogen produced and recovered may be a main product or a by-product. The dehydrogenation device 21 may be at least one device selected from the group consisting of a catalytic reforming device, an ethylene production device, a thermal decomposition device, and a catalytic decomposition device, or may be a combination of these devices. When the dehydrogenation device 21 is a catalytic reforming

device, any one of an ethylene production device, a hydrocracking device, a thermal decomposition device, and a catalytic decomposition device may be provided before the dehydrogenation device 21. It should be noted that catalytic reforming is distinguished from thermal decomposition and catalytic decomposition; thermal decomposition is a method of decomposing a hydrogenated hydrocarbon compound at a high temperature (for example, 480 to 565°C) without using a catalyst, and catalytic decomposition is a method of efficiently decomposing a specific hydrocarbon compound at a low temperature (for example, 495 to 565°C) using a catalyst. By producing and recovering hydrogen from the hydrogenated hydrocarbon compound using a thermal decomposition device or a catalytic decomposition device rather than a catalytic reforming device, the hydrogen content in the produced off-gas increases, and hydrogen can be produced efficiently.

[0045] When the dehydrogenation device 21 is a catalytic reforming device, the hydrogenated hydrocarbon compound is reformed in the presence of an alumina catalyst supporting platinum, rhenium, and the like, under conditions of a temperature of 450 to 550°C and a pressure of 0.5 to 7 MPa, to produce aromatic compounds and hydrogen. Examples of the aromatic compounds produced in the catalytic reforming device include a benzene, a toluene, and a xylene and the like. This series of processes, in which a hydrogenated hydrocarbon compound of a naphtha fraction is produced at the first location and then catalytic reforming is performed at the second location, is equivalent to the process of producing benzene, toluene, xylene, and the like at the second location using naphtha derived from crude oil as a raw material, and therefore

substantially no energy is consumed for the purpose of transporting the hydrogen carrier. Therefore, the cost of producing hydrogen as a by-product of benzene and the like at the second location does not newly arise, and hydrogen can be supplied inexpensively at the hydrogen demand site.

[0046] When the dehydrogenation device 21 is an ethylene production device, the hydrogenated hydrocarbon compound reacts with high-temperature steam to produce ethylene, hydrogen, and other by-products. Ethylene production is performed, for example, under conditions of a temperature of 800 to 900°C and a pressure of 0.1 to 0.3 MPa. This series of processes, in which a hydrogenated hydrocarbon compound of a naphtha fraction is produced at the first location and then processed in an ethylene production device at the second location, is equivalent to the process of producing ethylene at the second location using naphtha derived from crude oil as a raw material, and therefore substantially no energy is consumed for the purpose of transporting the hydrogen carrier. Therefore, the cost of producing hydrogen as a by-product of ethylene and the like does not arise, and hydrogen can be supplied inexpensively at the hydrogen demand site.

[0047] When the dehydrogenation device 21 is a thermal decomposition device, the hydrogenated hydrocarbon compound containing a residue fraction is decomposed at a high temperature to produce hydrocarbon gas and carbon materials such as solid carbon together with hydrogen. Thermal decomposition is performed, for example, under conditions of a temperature of 480 to 800°C and a pressure of 0.1 to 0.3 MPa. Examples of the hydrocarbon gas include a methane, an ethane, a propane, an

ethylene, and a propylene and the like. Carbon materials are distributed in the market as higher value-added products compared to hydrogenated hydrocarbon compounds, thereby improving the profitability of the thermal decomposition facility. In addition, this series of processes, in which a hydrogenated hydrocarbon compound containing a residue fraction is produced at the first location and then carbon materials are produced in a thermal decomposition facility at the second location, is equivalent to the process carried out for the purpose of producing carbon materials at the second location using a residue fraction derived from crude oil as a raw material, and therefore substantially no energy is consumed for the purpose of transporting the hydrogen carrier. Therefore, the cost of producing hydrogen as a by-product of carbon materials does not arise, and hydrogen can be supplied inexpensively at the hydrogen demand site.

[0048] When the dehydrogenation device 21 is a catalytic decomposition device, the hydrogenated hydrocarbon compound containing a residue fraction is decomposed by a catalyst to produce a hydrocarbon gas and a hydrocarbon mixture serving as a raw material for gasoline and diesel, together with hydrogen. Catalytic decomposition is performed, for example, under conditions of a temperature of 500 to 700°C and a pressure of 0.1 to 0.5 MPa. Examples of the catalyst include a zeolite-based catalyst, a platinum-based catalyst, and a palladium-based catalyst. Examples of the hydrocarbon gas include a methane, an ethane, a propane, an ethylene, and a propylene and the like. In addition, this series of processes, in which a hydrogenated hydrocarbon compound containing a residue fraction is

produced at the first location and then carbon materials are produced in a catalytic decomposition facility at the second location, is equivalent to the process carried out for the purpose of producing a hydrocarbon mixture serving as a raw material for gasoline and diesel at the second location using a residue fraction derived from crude oil as a raw material, and therefore substantially no energy is consumed for the purpose of transporting the hydrogen carrier. Therefore, the cost of producing hydrogen as a by-product of the hydrocarbon mixture serving as a raw material for gasoline and diesel does not arise, and hydrogen can be supplied inexpensively at the hydrogen demand site.

[0049] The dehydrogenation device 21 is connected to a transfer pipe L21 and a transfer pipe L22. The transfer pipe L21 transfers hydrogen, and the transfer pipe L22 transfers hydrocarbon compounds generated by dehydrogenation (for example, aromatic compounds generated by a catalytic reforming reaction).

[0050] After the dehydrogenation device 21, a separation device may be provided to increase the purity of the hydrogen and/or hydrocarbon compounds discharged from the dehydrogenation device 21. For example, when the dehydrogenation device 21 is at least one device selected from the group consisting of a catalytic reforming device, an ethylene production device, a thermal decomposition device, and a catalytic decomposition device, at least one separation device selected from the group consisting of a membrane separation device, an adsorption separation device, and a cryogenic separation device may be provided after the dehydrogenation device 21 to increase the purity of the hydrogen. It should be noted that in the related art, when the

dehydrogenation device is a device other than a catalytic reforming device, since the amount of hydrogen obtained from the hydrogen carrier is relatively small, a membrane separation device, an adsorption separation device, and a cryogenic separation device were not provided after the dehydrogenation device.

[0051] The hydrogen obtained from the dehydrogenation device 21 may be reacted with CO obtained by a reverse shift reaction with CO_2 to obtain a synthetic crude oil (hydrocarbon compound) by the Fischer-Tropsch method, may be reacted with CO_2 by a Sabatier reaction to obtain methane, may be reacted with nitrogen to obtain ammonia by the Haber-Bosch method, may be reacted with CO obtained by a reverse shift reaction with CO_2 to obtain methanol, or may be reacted with CO_2 to obtain methanol. The CO_2 may be procured from outside the dehydrogenation facility 20, or may be recovered from the process of the dehydrogenation facility 20.

[0052] The dehydrogenation device 21 is supplied with the hydrogenated hydrocarbon compound transported through the hydrogenation device (the hydrogenated hydrocarbon compound transported by the transportation means T1) and other hydrogenated hydrocarbon compounds other than the transported hydrogenated hydrocarbon compound, and the transported hydrogenated hydrocarbon compound and the other hydrogenated hydrocarbon compounds may be simultaneously dehydrogenated in the dehydrogenation device 21. In addition, when recovering hydrogen from the transported hydrogenated hydrocarbon compound and the other hydrogenated hydrocarbon compounds supplied to the dehydrogenation device 21, a mass fraction

of hydrogen generated from the transported hydrogenated hydrocarbon compound among the recovered hydrogen may be calculated, and the recovered hydrogen may be divided based on the mass fraction. As a result, for example, when the hydrogenation in the hydrogenation device 12 is performed using clean hydrogen, since the carbon intensity of a portion of the hydrogen recovered in the dehydrogenation device 21 becomes sufficiently low, it is possible to divide the hydrogen into hydrogen with a low carbon intensity (clean hydrogen) and other hydrogen (gray hydrogen). The mass fraction of hydrogen generated from the transported hydrogenated hydrocarbon compound among the recovered hydrogen can be calculated based on the flow rates and compositions of each component flowing into and out of the dehydrogenation device 21, the reaction rates of each reaction occurring in the dehydrogenation device 21, and the like.

[0053] In order to confirm that the produced, transported, and recovered hydrogen is clean hydrogen, the amount of clean hydrogen at each stage of production, transportation, and recovery may be calculated under mass balance management. Specifically, first, on the first location side, by using clean hydrogen for a portion of the hydrogen used for hydrogenation of the hydrocarbon mixture, a portion of the constituent molecules of the hydrogenated hydrocarbon compound becomes clean hydrogen. At this time, mass balance management of the amount of clean hydrogen on the first location side is performed from the amount of hydrogen present in the molecular structure of the hydrocarbon mixture and the amount of hydrogen present in the molecular structure of the hydrogenated hydrocarbon compound obtained by hydrogenation.

Next, on the second location side, a portion of the hydrogen recovered during the dehydrogenation of the hydrogenated hydrocarbon compound becomes clean hydrogen. At this time, mass balance management of the amount of clean hydrogen on the second location side is performed from the amount of hydrogen present in the molecular structure of the hydrogenated hydrocarbon compound to be dehydrogenated and the amount of hydrogen present in the molecular structure of the hydrocarbon mixture obtained by dehydrogenation. Based on this mass balance management, it is possible to divide the hydrogen into hydrogen with a low carbon intensity (clean hydrogen) and other hydrogen (gray hydrogen). In addition, through mass balance management, it is possible to freely allocate the environmental value of clean hydrogen having a low carbon intensity to output products (not only hydrogen but also hydrocarbon compounds), and it is possible to provide products with a low carbon intensity.

[0054] When the second location is a hydrogen consumption site, by producing hydrogen at the second location, surplus energy and costs for transporting hydrogen become unnecessary. In addition, when the hydrogenation in the hydrogenation device 12 is performed using clean hydrogen, the carbon intensity of the hydrogen recovered in the dehydrogenation device 21 becomes sufficiently low, and thus the hydrogen recovered at the second location becomes clean hydrogen.

[0055] Since the hydrocarbon compounds transferred through the transfer pipe L22 are higher value-added products than the hydrogenated hydrocarbon compound, they are consumed at the second location. Therefore, there is no need to transport the hydrocarbon compounds

back to the first location, and energy loss is small. In addition, since there is no need to repeatedly use the hydrogenated hydrocarbon compound as a hydrogen carrier, deterioration and loss of the hydrogen carrier do not occur.

[0056] The process up to dehydrogenation performed at the second location can be carried out using existing facilities in a hydrogen production plant. Therefore, the dehydrogenation facility 20 may be an existing facility, or may be partially or entirely a new facility.

[0057] [Method for Producing Hydrogen]

A method for finally producing hydrogen from a mixture containing an aromatic compound and an unsaturated hydrocarbon compound using the hydrogen production facility 100 will be described. That is, one embodiment of the present invention is a method for producing hydrogen that includes at least the following steps. The following method for producing hydrogen can refer as appropriate to the description relating to the hydrogen production facility 100. According to the method for producing hydrogen according to one embodiment of the present invention, deep hydrogenation (saturated hydrogenation) is performed on a mixture containing an aromatic compound and an unsaturated hydrocarbon compound, and the amount of hydrogen produced in the dehydrogenation facility 20 can be maximized.

(a) A hydrogenation step of performing hydrogenation and a treatment including at least one selected from the group consisting of desulfurization treatment, denitrogenation treatment, demetallization treatment, and hydrocracking on a mixture containing an aromatic compound and an unsaturated hydrocarbon compound in an

environment exceeding 250°C, to obtain a hydrogenated hydrocarbon compound.

(b) A transportation step of transporting the hydrogenated hydrocarbon compound obtained in step (a) from the first location to the second location.

(c) A dehydrogenation step of recovering hydrogen from the hydrogenated hydrocarbon compound transported in step (b).

[0058] <Step (a)>

Step (a) is a step of performing hydrogenation and a treatment including at least one selected from the group consisting of desulfurization treatment, denitrogenation treatment, demetallization treatment, and hydrocracking on a mixture containing an aromatic compound and an unsaturated hydrocarbon compound in an environment exceeding 250°C, to obtain a hydrogenated hydrocarbon compound. In step (a), the mixture containing an aromatic compound and an unsaturated hydrocarbon compound may be derived from crude oil or naphtha. In step (a), the aromatic compound may be a monocyclic aromatic compound or a polycyclic aromatic compound. In step (a), the unsaturated hydrocarbon compound may be an olefin.

[0059] Step (a) may include separating the mixture so that a proportion of the aromatic compound increases, hydrogenating the aromatic compound, and mixing the hydrogenated aromatic compound with a remainder of the mixture from which the aromatic compound has been separated. When the method for producing hydrogen includes such a step (a), it becomes easier to achieve maximum hydrogen saturation with respect to the mixture, the efficiency of the hydrogenation treatment is

improved, and the capital investment costs and operating costs of the facility can be minimized.

[0060] In step (a), the hydrogen used for hydrogenation may be clean hydrogen. Therefore, the method may further include, before step (a), at least one step selected from the group consisting of Step A of electrolyzing water to obtain hydrogen; Step B including steam-reforming methane to generate hydrogen and carbon dioxide, and separating the generated carbon dioxide and storing it underground; and Step C of thermally decomposing a gas containing a hydrocarbon such as natural gas (for example, methane) to obtain hydrogen, and step (a) may be a step of performing hydrogenation using the hydrogen obtained in any one of these Steps A to C.

[0061] <Step (b)>

Step (b) is a step of transporting the hydrogenated hydrocarbon compound from the first location to the second location. Step (b) may include temporarily storing the hydrogenated hydrocarbon compound in a storage container before and/or after transporting the hydrogenated hydrocarbon compound from the first location to the second location. The first location may be, for example, a clean hydrogen production site. The second location may be a hydrogen consumption site, or may be a site where valuable products generated from the hydrogenated hydrocarbon compound are used and consumed. The first location may be a region, a country, or the like where the production cost of clean hydrogen is lower than that of the second location. The second location may be a region, a country, or the like where the demand for clean hydrogen is high and where the consumption of petroleum and

petrochemical products generated from the hydrogenated hydrocarbon compound is greater than that of the first location, or where petroleum and petrochemical production facilities are well-established.

[0062] <Step (c)>

Step (c) is a step of recovering hydrogen from the transported hydrogenated hydrocarbon compound. Step (c) may be a step performed using at least one device selected from the group consisting of a catalytic reforming device, an ethylene production device, a thermal decomposition device, and a catalytic decomposition device.

[0063] When step (c) is a step performed using at least one device selected from the group consisting of an ethylene production device, a thermal decomposition device, and a catalytic decomposition device, the method for producing hydrogen may further include a separation step of purifying the hydrogen recovered in step (c) by at least one separation treatment selected from the group consisting of membrane separation, adsorption separation, and cryogenic separation, after step (c).

[0064] When step (c) is a step of recovering hydrogen from the transported hydrogenated hydrocarbon compound and other hydrogenated hydrocarbon compounds other than the transported hydrogenated hydrocarbon compound, the method may further include a calculation step of calculating a mass fraction of hydrogen generated from the transported hydrogenated hydrocarbon compound among the recovered hydrogen, and a step of dividing the recovered hydrogen based on the mass fraction, after the dehydrogenation step.

[0065] Step (c) may be a step of producing a hydrocarbon mixture containing at least one selected from the group consisting of ethylene,

propylene, benzene, toluene, xylene, and solid carbon, together with hydrogen.

[0066] Another embodiment of the present invention is a method for producing hydrogen that does not include the above-described step (a) but includes step (b) and step (c). For example, it is a method for producing hydrogen in which step (a) is not performed within a certain country, but step (b) and step (c) are performed, and step (a) may be performed in another country. That is, the method for producing hydrogen according to the other embodiment includes at least the following steps. In the method for producing hydrogen according to the other embodiment, hydrogen is produced using the facilities on the second location side in FIG. 1.

(b) A transportation step of transporting a hydrogenated hydrocarbon compound from the first location to the second location.

(c) A dehydrogenation step of recovering hydrogen from the hydrogenated hydrocarbon compound transported in step (b).

[0067] In addition, another embodiment of the present invention is a method for treating a hydrocarbon mixture that does not include the above-described step (c) but includes step (a) and step (b). For example, it is a method for treating a hydrocarbon mixture in which step (c) is not performed within a certain country, but step (a) and step (b) are performed, and step (c) may be performed in another country. That is, the method for treating a hydrocarbon mixture according to the other embodiment includes at least the following steps. In the method for treating a hydrocarbon mixture according to the other embodiment, the hydrocarbon mixture is treated using the facilities on the first location

side in FIG. 1.

(a) A hydrogenation step of performing hydrogenation and a treatment including at least one selected from the group consisting of desulfurization treatment, denitrogenation treatment, demetallization treatment, and hydrocracking on a mixture containing an aromatic compound and an unsaturated hydrocarbon compound in an environment exceeding 250°C, to obtain a hydrogenated hydrocarbon compound.

(b) A transportation step of transporting the hydrogenated hydrocarbon compound obtained in step (a) from the first location to the second location.

Reference Signs List

[0068] 10: Hydrogenation facility, 11: Treatment device, 12: Hydrogenation device, 13: Hydrogen generation device, 20: Dehydrogenation facility, 21: Dehydrogenation device, 22: Hydrogen utilization device, 23: Hydrogen generation device, T1: Transportation means, 100: Hydrogen production facility.

CLAIMS

[Claim 1]

A method for producing hydrogen, the method comprising:

a hydrogenation step of performing hydrogenation and a treatment comprising at least one selected from the group consisting of desulfurization treatment, denitrogenation treatment, demetallization treatment, and hydrocracking on a mixture comprising an aromatic compound and an unsaturated hydrocarbon compound in an environment exceeding 250°C, to obtain a hydrogenated hydrocarbon compound;

a transportation step of transporting the hydrogenated hydrocarbon compound from a first location to a second location; and

a dehydrogenation step of recovering hydrogen from the transported hydrogenated hydrocarbon compound.

[Claim 2]

The method for producing hydrogen according to claim 1, wherein the hydrogenation step comprises:

separating the mixture so that a proportion of the aromatic compound increases;

hydrogenating the aromatic compound; and

mixing the hydrogenated aromatic compound with a remainder of the mixture from which the aromatic compound has been separated.

[Claim 3]

The method for producing hydrogen according to claim 1 or 2, wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having a 90 volume% distillation temperature of ASTM D1160

of 360°C or higher and an RVP of 13 psi or less, in which a total mass concentration of aromatic compounds in compounds having an NBP of 300°C or lower comprised in the hydrocarbon mixture is 1/10 or less of a total mass concentration of cyclic alkanes.

[Claim 4]

The method for producing hydrogen according to claim 1 or 2, wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having an End Boiling Point of ASTM D86 of 230°C or lower, in which a total mass concentration of benzene, toluene, xylene, and ethylbenzene is 1/10 or less of a total mass concentration of cyclohexane, methylcyclohexane, dimethylcyclohexane, and ethylcyclohexane in the hydrocarbon mixture, and a total mass concentration of paraffin compounds comprising hexane and heptane is 1/10 or more of a total mass concentration of the hydrogenated hydrocarbon mixture.

[Claim 5]

The method for producing hydrogen according to claim 1 or 2, wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having a 5 volume% distillation temperature of ASTM D1160 of 300°C or higher, in which a total mass concentration of aromatic compounds comprised in the hydrocarbon mixture is 1/2 or less of a total mass concentration of cyclic alkanes.

[Claim 6]

The method for producing hydrogen according to claim 1 or 2, wherein the dehydrogenation step is a step performed using at least one device selected from the group consisting of a catalytic reforming

device, an ethylene production device, a thermal decomposition device, and a catalytic decomposition device.

[Claim 7]

The method for producing hydrogen according to claim 1 or 2, wherein the dehydrogenation step is a step performed using at least one device selected from the group consisting of an ethylene production device, a thermal decomposition device, and a catalytic decomposition device, and

the method further comprises a separation step of purifying the hydrogen by at least one separation treatment selected from the group consisting of membrane separation, adsorption separation, and cryogenic separation, after the dehydrogenation step.

[Claim 8]

The method for producing hydrogen according to claim 1 or 2, wherein the dehydrogenation step is a step of recovering hydrogen from the transported hydrogenated hydrocarbon compound and other hydrogenated hydrocarbon compounds other than the transported hydrogenated hydrocarbon compound, and

the method further comprises:

a calculation step of calculating a mass fraction of hydrogen generated from the transported hydrogenated hydrocarbon compound among the recovered hydrogen; and

a step of dividing the recovered hydrogen based on the mass fraction, after the dehydrogenation step.

[Claim 9]

A method for treating a hydrocarbon mixture, the method

comprising:

a hydrogenation step of performing hydrogenation and a treatment comprising at least one selected from the group consisting of desulfurization treatment, denitrogenation treatment, demetallization treatment, and hydrocracking on a mixture comprising an aromatic compound and an unsaturated hydrocarbon compound in an environment exceeding 250°C, to obtain a hydrogenated hydrocarbon compound; and

a transportation step of transporting the hydrogenated hydrocarbon compound from a first location to a second location.

[Claim 10]

The method for treating a hydrocarbon mixture according to claim 9, wherein the hydrogenation step comprises:

separating the mixture so that a proportion of the aromatic compound increases;

hydrogenating the aromatic compound; and

mixing the hydrogenated aromatic compound with a remainder of the mixture from which the aromatic compound has been separated.

[Claim 11]

The method for treating a hydrocarbon mixture according to claim 9 or 10, wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having a 90 volume% distillation temperature of ASTM D1160 of 360°C or higher and an RVP of 13 psi or less, in which a total mass concentration of aromatic compounds in compounds having an NBP of 300°C or lower comprised in the hydrocarbon mixture is 1/10 or less of a total mass concentration of cyclic alkanes.

[Claim 12]

The method for treating a hydrocarbon mixture according to claim 9 or 10, wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having an End Boiling Point of ASTM D86 of 230°C or lower, in which a total mass concentration of benzene, toluene, xylene, and ethylbenzene is 1/10 or less of a total mass concentration of cyclohexane, methylcyclohexane, dimethylcyclohexane, and ethylcyclohexane in the hydrocarbon mixture, and a concentration of paraffin compounds comprising hexane and heptane is 1/10 or more of a total mass concentration of the hydrogenated hydrocarbon mixture.

[Claim 13]

The method for treating a hydrocarbon mixture according to claim 9 or 10, wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having a 5 volume% distillation temperature of ASTM D1160 of 300°C or higher, in which a total mass concentration of aromatic compounds comprised in the hydrocarbon mixture is 1/2 or less of a total mass concentration of cyclic alkanes.

[Claim 14]

A method for producing hydrogen, the method comprising:

a transportation step of transporting a hydrogenated hydrocarbon compound from a first location to a second location; and

a dehydrogenation step of recovering hydrogen from the transported hydrogenated hydrocarbon compound.

[Claim 15]

The method for producing hydrogen according to claim 14, wherein the hydrogenated hydrocarbon compound is a hydrocarbon

mixture having a 90 volume% distillation temperature of ASTM D1160 of 360°C or higher and an RVP of 13 psi or less, in which a total mass concentration of aromatic compounds in compounds having an NBP of 300°C or lower comprised in the hydrocarbon mixture is 1/10 or less of a total mass concentration of cyclic alkanes.

[Claim 16]

The method for producing hydrogen according to claim 14, wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having an End Boiling Point of ASTM D86 of 230°C or lower, in which a total mass concentration of benzene, toluene, xylene, and ethylbenzene is 1/10 or less of a total mass concentration of cyclohexane, methylcyclohexane, dimethylcyclohexane, and ethylcyclohexane in the hydrocarbon mixture, and a total mass concentration of paraffin compounds comprising hexane and heptane is 1/10 or more of a total mass concentration of the hydrogenated hydrocarbon mixture.

[Claim 17]

The method for producing hydrogen according to claim 14, wherein the hydrogenated hydrocarbon compound is a hydrocarbon mixture having a 5 volume% distillation temperature of ASTM D1160 of 300°C or higher, in which a total mass concentration of aromatic compounds comprised in the hydrocarbon mixture is 1/2 or less of a total mass concentration of cyclic alkanes.

[Claim 18]

The method for producing hydrogen according to any one of claims 14 to 17, wherein the dehydrogenation step is a step performed

using at least one device selected from the group consisting of a catalytic reforming device, an ethylene production device, a thermal decomposition device, and a catalytic decomposition device.

[Claim 19]

The method for producing hydrogen according to any one of claims 14 to 17, wherein the dehydrogenation step is a step performed using at least one device selected from the group consisting of an ethylene production device, a thermal decomposition device, and a catalytic decomposition device, and

the method further comprises a separation step of purifying the hydrogen by at least one separation treatment selected from the group consisting of membrane separation, adsorption separation, and cryogenic separation, after the dehydrogenation step.

[Claim 20]

The method for producing hydrogen according to any one of claims 14 to 17, wherein the dehydrogenation step is a step of recovering hydrogen from the transported hydrogenated hydrocarbon compound and other hydrogenated hydrocarbon compounds other than the transported hydrogenated hydrocarbon compound, and

the method further comprises:

a calculation step of calculating a mass fraction of hydrogen generated from the transported hydrogenated hydrocarbon compound among the recovered hydrogen; and

a step of dividing the recovered hydrogen based on the mass fraction, after the dehydrogenation step.