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(54) Titre : PROCEDE DE PRODUCTION D'UNE HUILE VALORISEE ET APPAREILLAGE SERVANT A SA PRODUCTION

(54) Title: METHOD FOR PRODUCING UPGRADED OIL, AND APPARATUS FOR PRODUCING UPGRADED OIL

(57) Abrégé/Abstract:
[Problem] Upon producing an upgraded oil by utilizing supercritical water, provided include a method for producing an upgraded oil and an apparatus for producing an upgraded oil, which are capable of providing an upgraded oil with a high yield. [Means for Resolution] A reactor 1 is maintained to a temperature and a pressure that are higher than a critical point of water, and while thermal cracking of the heavy oil is occurred by making the heavy oil and the supercritical water in contact with each other, a first phase containing a heavy oil component obtained by thermal cracking of the heavy oil and the supercritical water dissolved in the heavy oil component is formed at a lower part, whereas a second phase containing the supercritical water and a light oil component extracted by the supercritical water is formed at an upper part. A effluent from the first phase is withdrawn from the first phase through the lower part of the reactor, for suppressing formation of coke in the heavy oil component, and a effluent from the second phase is withdrawn from the second phase through the upper part of the reactor, for suppressing formation of gas in the light oil component. In a mixing part 2, the heavy oil component of the effluent from the first phase is mixed into the light oil component of the effluent from the second phase, thereby providing an upgraded oil.

[Designation of Document]

Abstract

[Abstract]

[Problem]

Upon producing an upgraded oil by utilizing supercritical water, provided include a method for producing an upgraded oil and an apparatus for producing an upgraded oil, which are capable of providing an upgraded oil with a high yield.

[Means for Resolution]

A reactor 1 is maintained to a temperature and a pressure that are higher than a critical point of water, and while thermal cracking of the heavy oil is occurred by making the heavy oil and the supercritical water in contact with each other, a first phase containing a heavy oil component obtained by thermal cracking of the heavy oil and the supercritical water dissolved in the heavy oil component is formed at a lower part, whereas a second phase containing the supercritical water and a light oil component extracted by the supercritical water is formed at an upper part. A effluent from the first phase is withdrawn from the first phase through the lower part of the reactor, for suppressing formation of coke in the heavy oil component, and a effluent from the second phase is withdrawn from the second phase through the upper part of the reactor, for suppressing formation of gas in the light oil component.

In a mixing part 2, the heavy oil component of the effluent from the first phase is mixed into the light oil component of the effluent from the second phase, thereby providing an upgraded oil.

[Selected Drawing]

Fig. 1

[Designation of Document]

Specification

[Title of the Invention]

METHOD FOR PRODUCING UPGRADED OIL, AND APPARATUS FOR PRODUCING UPGRADED OIL

[Technical Field]

[0001]

The present invention relates to a technique for producing an upgraded oil from a heavy oil by utilizing supercritical water.

[Background Art]

[0002]

Under the expected increase of the demand of a crude oil mainly in developing countries including China and India, the production of a light crude oil, which has been utilized, is now encountering the maximum, and thus there is an increasing necessity of utilization of a heavy crude oil and an extra heavy crude oil, which have been less used. Canadian oil sand bitumen and Venezuelan Orinoco tar as the extra heavy oil have been established for production technique, and the production amounts thereof are being increased.

[0003]

An extra heavy crude oil has very high density and viscosity and cannot be transported with pipelines or the like for transporting from oil wells in production areas to oil

factories. At the wellhead, accordingly, two measures are selected, i.e., a dilution method where a diluent is mixed with the crude oil to decrease the viscosity, and an upgrading method where a plant for performing thermal cracking or hydrogenation, which is referred to as an upgrader, is provided next to the well to produce a synthetic light crude oil.

[0004]

However, the dilution method has a problem of necessitating a sufficient amount of the diluent such as condensates and a problem of increasing the transportation cost due to the increase of the transportation amount by dilution. The upgrading method has a problem that the method cannot be managed economically except for a vicinity of a large-scale oil field since a large-scale plant like an oil factory is necessarily provided at the wellhead, and also has a problem of processing by-products including coke and sulfur and a problem of necessitating hydrogen required for refining.

[0005]

The known upgrading techniques of heavy oil include a thermal cracking process, such as a delayed coker and a fluid coker, and a hydrocracking process, such as H-oil and LC-fining. In the thermal cracking process, a heavy oil is thermally cracked to produce a cracked oil, gas and coke. The thermal cracking process has a problem that the by-products produced in a large amount including coke and sulfur are necessarily

stored outdoors if there is no purpose of the by-products.

[0006]

The hydrocracking process is a technique of cracking a heavy oil with a catalyst in under a high temperature and high hydrogen pressure condition. The hydrocracking process requires a large amount of hydrogen and thus requires naphtha or natural gas, which brings about a problem of supply thereof. Furthermore, it is necessary to deal with supply of the catalyst and disposal of the used catalyst.

As described above, the known techniques involve problems in treatment of by-products, production of hydrogen, supply of catalysts, and disposal of waste catalysts.

[0007]

In view of the problems, the present inventors pay attention to a technique of producing a synthetic crude oil (upgraded oil) capable of being transported with pipelines through a simple upgrading scheme without a diluent, by upgrading a heavy crude oil or an extra heavy crude oil (which may be hereinafter referred to as a heavy oil) by utilizing supercritical water. In the technique, the thermal cracking reaction of the heavy oil by making the heavy oil in contact with the supercritical water and the extraction of the light oil component produced by thermal cracking to the side of the supercritical water are performed simultaneously in the reactor, and the light oil component thus extracted is

recovered to provide a synthetic crude oil capable of being transported with pipelines. The heavy oil component that is not extracted to supercritical water can be used as a residual oil for such purposes as a boiler fuel.

[0008]

As a technique of refining a heavy oil by utilizing supercritical water, for example, Patent Document 1 describes a technique, in which a heavy oil fed downward vertically to an upper part of a rector and supercritical water (or subcritical water) fed to a lower part thereof are made in contact with each other for refining the heavy oil in the reactor, and thereby the light oil component dissolved the supercritical water and the heavy oil component insoluble therein are separated from each other.

[0009]

Patent Document 2 proposes an upgrading apparatus containing a primary thermal cracking part in a lower part of a vertical reactor where a heavy oil and supercritical water are heated and mixed to crack a part of the raw material into a light component, which is then vaporized, and a secondary thermal cracking part over a center part to an upper part in the vertical direction of the same reactor where a part of the vaporized light component is further cracked into an upgraded component. In the primary thermal cracking part, a thermal cracking vessel is provided in the reactor for reacting the

heavy oil therein, and the overflow liquid that is not thermally cracked is discharged as a residual oil from the lower part of the reactor. In addition, Patent Document 3 describes a technique, in which a heavy oil and supercritical water are in contact with each other in a reactor to produce an upgraded oil emulsion and coke, and the upgraded oil emulsion is continuously withdrawn, whereas the coke is withdrawn intermittently.

[Related Art Documents]

[Patent Documents]

[0010]

[Patent Document 1] Japanese Patent No. 4,171,062, claim 1, paragraphs 0030 to 0033, Fig. 1

[Patent Document 2] JP-A-2008-208170, claim 1, paragraphs 0012 to 0017, Fig. 1

[Patent Document 3] JP-A-2007-51224, claim 1, paragraphs 0024 to 0030, Fig. 3

[Summary of the Invention]

[Problems that the Invention is to Solve]

[0011]

In the technique described in Patent Document 1 among the related art documents, a heavy oil and supercritical water are made in contact with each other to dissolve a light oil component into the side of supercritical water, and thereby heavy metals, such as vanadium, contained in the heavy oil are

removed to provide a gas turbine fuel that is hard to cause high temperature corrosion. The heavy metals contained in the heavy oil are concentrated into a heavy oil component that is insoluble in supercritical water, and the heavy oil component is used as a fuel of a boiler or the like. The technique aims to remove the heavy metals but it does not aim to crack the heavy oil, and thus the residence time of the heavy oil component in the reactor is short. Accordingly, the heavy oil is insufficiently cracked and is fail to increase the yield of the synthetic crude oil aiming at transportation with pipelines.

[0012]

According to the technique described in Patent Document 2, the primary thermal cracking part is heated to 380 to 450°C, and the secondary cracking part provided on the upper part thereof is heated to a higher temperature of from 450 to 500°C than the primary thermal cracking part, whereby a heavy oil in contact with supercritical water is cracked by two steps, i.e., into a light oil component and further to an upgraded component. When the cracking of a light component proceeds positively as in this technique, however, the increase of gas production amount (i.e., decrease of the liquid yield) due to excessive cracking and the increase of the olefin concentration in the light component may occur, and the technique is not suitable for production of a synthetic crude

oil.

[0013]

In the technique described in Patent Document 3, the operation is performed by positively selecting the condition where coke is formed, and thus the technique has a problem of treating coke. Furthermore, there may be possibilities that under the severe condition where coke is formed, the gas production amount is increased (i.e., the liquid yield is decreased) due to excessive cracking of the light oil component, the olefin concentration in the upgraded oil may be increased.

[0014]

The techniques of the related art thus cannot increase sufficiently the yield of the synthetic crude oil from the heavy oil due to the insufficient cracking of the heavy oil, the decomposition of the light component into gas, the production of coke from the heavy oil, and the like. The invention has been developed under the circumstances, and an object thereof is, upon producing an upgraded oil by utilizing supercritical water, to provide a method for producing an upgraded oil and an apparatus for producing an upgraded oil, which are capable of providing an upgraded oil with a high yield.

[Means for solving the Problems]

[0015]

Measures for solving the problems are shown below.

(1) A method for producing an upgraded oil,

containing:

a step of feeding a heavy oil to a reactor;

a step of feeding supercritical water to the reactor;

a step of thermal cracking of the heavy oil by making the heavy oil and the supercritical water in contact with each other while maintaining conditions in the reactor to a temperature and a pressure that are higher than a critical point of water;

a step of forming at a lower part of the reactor a first phase containing a heavy oil component obtained by thermal cracking of the heavy oil and the supercritical water dissolved in the heavy oil component, and forming at an upper part of the reactor a second phase containing the supercritical water and a light oil component extracted by the supercritical water;

a step of withdrawing a effluent from the first phase at the lower part of the reactor, for suppressing formation of coke in the heavy oil component;

a step of withdrawing a effluent from the second phase at the upper part of the reactor, for suppressing formation of gas in the light oil component; and

a step of providing an upgraded oil by mixing the heavy oil component of the effluent from the first phase into the light oil component of the effluent from the second phase.

(2) The method for producing an upgraded oil according to the item (1), wherein

the method contains:

a step of flash distillation of the effluent from the first phase to separate into a mixed vapor of a light oil fraction contained in the heavy oil component of the first phase and water, and a remaining heavy oil component;

a step of separating the mixed vapor into the light oil fraction and water by cooling the mixed vapor; and

a step of mixing the light oil fraction into the light oil component in the effluent from the second phase, and

in the step of providing an upgraded oil, the heavy oil component produced by flash distillation is mixed into the light oil component.

(3) The method for producing an upgraded oil according to the item (1) or (2), wherein

the method contains:

a step of separating the effluent from the second phase into the light oil component and water, and

in the step of providing an upgraded oil, the heavy oil component is mixed into the light oil component having been separated from water.

(4) The method for producing an upgraded oil according to any one of the items (1) to (3), wherein an amount of the heavy oil component that is mixed into the light oil component is in a range that satisfies a standard of specific gravity or viscosity that is prescribed to the upgraded oil.

(5) The method for producing an upgraded oil according to any one of the items (1) to (4), wherein the method contains a step of controlling a withdrawing amount of the effluent from the first phase to such an amount that a residence time of the effluent from the first phase is one of:

(i) a residence time in a range of from 3 to 95 minutes,

(ii) a residence time that proceeds thermal cracking of the heavy oil in such a range that a formation amount of coke is from 0 to 20% by weight of the heavy oil component, and

(iii) a residence time that proceeds thermal cracking of the heavy oil to such an extent that a kinematic viscosity of the heavy oil component at 350°C is 3.0×10^{-5} m^2/s or less.

(6) The method for producing an upgraded oil according to any one of the items (1) to (5), wherein the method contains a step of controlling a feeding amount of the supercritical water to the reactor to such an amount that a residence time of the effluent from the second phase is one of:

(i) the second residence time in a range of from 1 to 25 minutes, for suppressing excessive cracking of the light oil component,

(ii) a residence time that proceeds thermal cracking of the heavy oil in such a range that a formation amount of gas due to excessive cracking is from 0 to 5% by weight of the heavy oil, and

(iii) a residence time that proceeds thermal cracking of the heavy oil to such an extent that a kinematic viscosity of the light oil component at 10°C is 5.0×10^{-3} m^2/s or less.

(7) The method for producing an upgraded oil according to any one of the items (1) to (6), wherein the heavy oil is selected from the group of heavy oils consisting of oil sand bitumen, Orinoco tar, a residual oil of atmospheric distillation, and a residual oil of reduced pressure distillation.

(8) An apparatus for producing an upgraded oil, containing:

a reactor that is maintained to a temperature and a pressure that are higher than a critical point of water, in which while proceeding thermal cracking of a heavy oil by making the heavy oil and supercritical water in contact with each other, a first phase containing a heavy oil component obtained by thermal cracking of the heavy oil and the supercritical water dissolved in the heavy oil component is formed at a lower part thereof, and a second phase containing the supercritical water and a light oil component extracted by the supercritical water is formed at an upper part thereof;

a first flow rate controlling unit that withdraws a effluent from the first phase containing the heavy oil component and the supercritical water dissolved in the heavy oil component in the first phase at the lower part of the reactor,

for suppressing formation of coke in the heavy oil component;

a second flow rate controlling unit that withdraws a effluent from the second phase at the upper part of the reactor, for suppressing formation of gas in the light oil component; and

a mixing part that mixes the heavy oil component of the effluent from the first phase into the light oil component of the effluent from the second phase withdrawn from the upper part of the reactor, thereby providing an upgraded oil.

(9) The apparatus for producing an upgraded oil according to the item (8), wherein

the apparatus contains:

a flashing part that conduct flash distillation of the effluent from the first phase to separate into a mixed vapor of a light oil fraction contained in the heavy oil component of the first phase and water, and a remaining heavy oil component;

a first separating part that separates the mixed vapor into the light oil fraction and water by cooling the mixed vapor; and

a light oil fraction mixing part that mixes the light oil fraction into the light oil component in the effluent from the second phase, and

in the mixing part, the heavy oil component having been obtained by flash distillation is mixed into the light oil

component.

(10) The apparatus for producing an upgraded oil according to the item (8) or (9), wherein

The apparatus contains:

a second separating part that separates the effluent from the second phase into the light oil component and water, and

in the mixing part, the heavy oil component is mixed into the light oil component having been separated from water.

(11) The apparatus for producing an upgraded oil according to any one of the items (8) to (10), wherein an amount of the heavy oil component that is mixed into the light oil component is in a range that satisfies a standard of specific gravity or viscosity that is prescribed to the upgraded oil.

(12) The apparatus for producing an upgraded oil according to any one of the items (8) to (11), wherein the apparatus contains a controlling part that controls a withdrawing amount of the effluent from the first phase to such an amount that a residence time of the effluent from the first phase is one of:

(i) a residence time in a range of from 3 to 95 minutes,

(ii) a residence time that proceeds thermal cracking of the heavy oil in such a range that a formation amount of coke is from 0 to 20% by weight of the heavy oil component, and

(iii) a residence time that proceeds thermal cracking

of the heavy oil to such an extent that a kinematic viscosity of the heavy oil component at 350°C is 3.0×10^{-5} m^2/s or less.

(13) The apparatus for producing an upgraded oil according to any one of the items (8) to (12), wherein the apparatus contains a controlling part that controls a feeding amount of the supercritical water to the reactor to such an amount that a residence time of the effluent from the second phase is one of:

(i) the second residence time in a range of from 1 to 25 minutes, for suppressing excessive cracking of the light oil component,

(ii) a residence time that proceeds thermal cracking of the heavy oil in such a range that a formation amount of gas due to excessive cracking is from 0 to 5% by weight of the heavy oil, and

(iii) a residence time that proceeds thermal cracking of the heavy oil to such an extent that a kinematic viscosity of the light oil component at 10°C is 5.0×10^{-3} m^2/s or less.

(14) The apparatus for producing an upgraded oil according to any one of the items (8) to (13), wherein the heavy oil is selected from the group of heavy oils consisting of oil sand bitumen, Orinoco tar, a residual oil of atmospheric distillation, and a residual oil of reduced pressure distillation.

[Advantages of the Invention]

[0017]

According to the invention, a heavy oil is thermally cracked into a heavy oil component and a light oil component, by making the heavy oil into contact with supercritical water, and the heavy oil component is mixed into the light oil component, thereby producing an upgraded oil, whereby an upgraded oil can be obtained with a high yield.

[Brief Description of the Drawings]

[0018]

[Fig. 1]

The figure shows a basic structural diagram of an apparatus for producing an upgraded oil according to an embodiment.

[Fig. 2]

The figure shows an example of a structure of a reactor provided in the apparatus for producing an upgraded oil.

[Fig. 3]

The figure shows a first structural example of a mixing part provided in the apparatus for producing an upgraded oil.

[Fig. 4]

The figure shows a structural second example of the mixing part.

[Fig. 5]

The figure shows a first structural example of the apparatus for producing an upgraded oil.

[Fig. 6]

The figure shows a second structural example of the apparatus for producing an upgraded oil.

[Mode for carrying out the Invention]

[0019]

Basic Structure

The basic structure of the apparatus for producing an upgraded oil according to one embodiment of the invention will be described. The apparatus for forming an upgraded oil is installed at the wellhead where a highly viscous crude oil such as oil sand bitumen and Orinoco tar is produced, and produces a synthetic crude oil with low density and low viscosity from the heavy oil.

[0020]

The apparatus for producing an upgraded oil has, as shown in Fig. 1, a reactor 1, in which a heavy oil and supercritical water are made in contact with each other to perform thermal cracking of the heavy oil, and a heavy oil component and a light oil component thus obtained are withdrawn separately, and a mixing part 2, in which a part or the whole of the heavy oil component is mixed into the light oil component obtained from the reactor 1, thereby producing a synthetic crude oil as the upgraded oil. The resulting synthetic crude oil is transported to an oil factory and processed into a fuel oil, a raw material of chemicals, and the like through various

refinery processes including distillation, reformation, cracking and desulfurization. The heavy oil component that is not mixed into the light oil component is used as a residue for such purposes as a boiler fuel.

[0021]

Reactor

Fig. 2 schematically shows an internal structure of a reactor 10 constituting the reactor 1 and a structure of a control system provided in the reactor 10. In the reactor 10, a heavy oil having been heated and pressurized is made, for example, in countercurrent contact, with supercritical water for thermal cracking of the heavy oil, and a light oil component and a heavy oil component obtained thereby are withdrawn separately. A heavy oil feeding line 110 that feeds the heavy oil having been heated and pressurized is connected to the upper side of the reactor 10. A supercritical water feeding line 120 that feeds the supercritical water having been heated and pressurized is connected to the lower side of the reactor 10. Upon contact of both the fluids in the reactor 10, the heavy oil is thermally cracked with the heat brought by the supercritical water, thereby lighten the entire heavy oil. In Fig. 2, numeral 101 denotes a feeding nozzle of the heavy oil, and 102 denotes a feeding nozzle of the supercritical water.

[0022]

Upon contact of the fluids, a light oil component

contained in the heavy oil in advance is extracted to the supercritical water, a heavy oil component that remains but is not extracted to the supercritical water is thermally cracked, and a light oil component formed through the thermal cracking is extracted to the supercritical water, whereby the fluids form two separated phases, i.e., a continuous phase containing the supercritical water and the light oil components (which may be hereinafter referred to as the second phase), and a continuous phase containing the heavy oil component that is not extracted to the supercritical water (which may be hereinafter referred to as the first phase). The heavy oil component has a larger specific gravity than the mixed fluid of the supercritical water and the light oil component, and therefore, the first phase is formed in the lower part of the reactor 10, whereas the second phase is formed in the upper part of the reactor 10.

[0023]

In an actual operation, the heavy oil component constituting the first phase contains the supercritical water dissolved therein in an amount of approximately 3 to 100% by weight of the heavy oil component (based on the dry state containing no water) while depending on the kind of the heavy oil and the temperature and pressure conditions of the reactor 10. In this point of view, it can be understood that the first phase is constituted by the mixed fluid of the heavy oil

component and the supercritical water. Upon dissolving the supercritical water into the heavy oil component, water molecules penetrate among molecules, for example, of polycyclic aromatic compounds, constituting the heavy oil component having been subjected to thermal cracking, and thereby the cage effect is exerted, in which formation of asphaltene due to polycondensation of the polycyclic aromatic compounds and formation of coke due to polycondensation of asphaltene are suppressed.

[0024]

In the reactor 10 according to the embodiment, the supercritical water is fed from the supercritical water feeding nozzle 102 into the first phase in the lower part, and the heavy oil is fed from the heavy oil feeding nozzle 101 into the second phase in the upper part. The extraction of the light oil component to the supercritical water and the dissolution of the supercritical water to the heavy oil component proceed at the interface of the supercritical water moving upward (as a dispersed phase) in the first phase, the interface of the heavy oil moving downward (as a dispersed phase) in the second phase, and the interface between the first phase and the second phase.

[0025]

The inventors have comprehended that the upward velocity of the supercritical water moving upward in the first phase

and the downward velocity of the heavy oil moving downward in the second phase are considerably large, and the supercritical water and the heavy oil pass through the first and second phases, respectively, within a period, for example, of from several seconds to several tens of seconds. Accordingly, the actual thermal cracking of the heavy oil proceeds in such a manner that the thermal cracking of the heavy oil component proceeds in the first phase, the light oil component formed by the thermal cracking is extracted to the second phase, and further thermal cracking of the light oil component having been in the second phase and the light oil component fed from the first phase proceeds in the second phase.

[0026]

As shown in Fig. 2, a heavy oil component withdrawing line 140 that withdraws the fluid constituting the first phase (i.e., the mixed fluid of the heavy oil component and the supercritical water) is connected to the bottom of the reactor 10. The heavy oil component withdrawing line 140 has installed thereon a flow rate controlling valve 142 that controls the withdrawing amount of the fluid from the first phase. The fluid withdrawn from the heavy oil withdrawing line 140 is cooled with a cooling device or the like for terminating the thermal cracking. A light oil component withdrawing line 130 that withdraws the fluid constituting the second phase (i.e., the mixed fluid of the light oil component and the supercritical

water) is connected to the top of the reactor 10. The light oil component withdrawing line 130 has installed thereon a pressure controlling valve 131 that controls the pressure inside the reactor 10, for example, to from 25 to 30 MPa. The fluid withdrawn from the light oil component withdrawing line 130 is also cooled with a cooling device or the like for terminating the thermal cracking of the light oil component.

[0027]

Controlling Mechanism

According to the thermal cracking mechanism described above, the extent of the thermal cracking of the heavy oil component can be controlled with the residence time of the mixed fluid of the heavy oil component and the supercritical water dissolved in the heavy oil component (which is hereinafter referred to as the effluent from the first phase) in the first phase. The yield of the light oil component is increased by increasing the extent of the thermal cracking of the heavy oil, and when the cracking of the heavy oil component is performed suitably under the conditions where the cage effect is exerted by dissolving the supercritical water in the heavy oil component, the viscosity of the heavy oil component is decreased, which facilitates the handling on using as a boiler fuel and the handling of the synthetic crude oil obtained by mixing with the light oil component. When the thermal cracking proceeds to such an extent that the cage effect is cancelled,

on the other hand, coke is formed in the heavy oil component.

[0028]

The apparatus for producing an upgraded oil according to the embodiment thus has a mechanism that controls the residence time of the effluent from the first phase for performing the thermal cracking of the heavy oil component to such an extent that the heavy oil component as the residual oil has a kinematic viscosity at 350°C, for example, of 3.0 $\times 10^{-5}$ m^2/s or less (30 cSt or less), and coke is suppressed from being formed (for example, to such an extent that the formation amount of coke is in a range of from 0 to 20% by weight of the heavy oil component).

[0029]

The extent of the thermal cracking of the light oil component can be controlled with the residence time of the mixed fluid of the supercritical water and the light oil component extracted to the supercritical water (which is hereinafter referred to as the effluent from the second phase) in the second phase. The kinematic viscosity of the light oil component is decreased by increasing the extent of the thermal cracking, which enables, for example, transportation of the synthetic crude oil without any special heating equipment in cold regions. When the light oil component is excessively cracked, on the other hand, the gas formation amount from the light oil component is increased, which decreases the yield of the

synthetic crude oil.

[0030]

The apparatus for forming an upgraded oil thus has a mechanism that controls the residence time of the effluent from the second phase for performing the thermal cracking of the light oil component to such an extent that the sole light oil component or the synthetic crude oil obtained by mixing with the heavy oil component has a kinematic viscosity at 10°C, for example, of 5.0×10^{-3} m^2/s or less (5,000 cSt or less), and formation of gas is suppressed. In the apparatus for producing an upgraded oil of the embodiment, the synthetic crude oil is produced by mixing the heavy oil component to the light oil component, and therefore, for making the kinematic viscosity of the synthetic crude oil after mixing with the heavy oil component of 5.0×10^{-3} m^2/s or less (5,000 cSt or less), the residence time of the effluent from the second phase is controlled to provide a further lower kinematic viscosity for the sole light oil component, which is mixed with the heavy oil component having a relatively large kinematic viscosity.

[0031]

For example, when the residence time of the effluent from the first phase is represented by θpitch, the residence time of the effluent from the second phase is represented by θLt, the feeding amount per unit time of the heavy oil from the heavy oil feeding line 110 is represented by FOin, the feeding amount

per unit time of the supercritical water from the supercritical water feeding line 120 is represented by Fwin, the withdrawing amount per unit time of the effluent from the first phase at the heavy oil component withdrawing line 140 is represented by FW1 + Pitch, and the withdrawing amount per unit time of the effluent from the second phase from the light oil component withdrawing line 130 is represented by FW2 + Lt, the balance among the feed and withdrawal of the fluids to the reactor 10 is shown by the following expression (2):

$$FOin + Fwin = FW1 + Pitch + FW2 + Lt \qquad (2)$$

[0032]

The proportion of the light oil component that is extracted to the second phase varies depending on the nature of the heavy oil, the temperature and pressure conditions of the reactor 10, and the extent of the thermal cracking of the heavy oil component, and in this embodiment, such a case is considered that uses a heavy oil providing, for example, a fraction that is lighter than VGO (vacuumed gas oil) having a boiling point of 540°C is extracted as the light oil component to the supercritical water, and a fraction that corresponds to VR (vacuumed residue) having a boiling point higher than 540°C is withdrawn as the heavy oil component that is not extracted to the supercritical water. In this embodiment, it

is assumed that the yield ratio of VGO (i.e., the yield ratio of VR) can be handled substantially constant by controlling θpitch to a variation range, for example, of approximately ±1 minute of the target value for controlling the extent of the thermal cracking within a certain range.

[0033]

When the flow rate of the fraction of the heavy oil fed to the reactor 10 that is withdrawn as the heavy oil component is represented by FPitch, the flow rate of the fraction of the heavy oil that is withdrawn as the light oil component is represented by FLt, the flow rate of the fraction of the supercritical water fed to the reactor 10 that is dissolved in the heavy oil component and withdrawn from the first phase is represented by Fw1, and the flow rate of the fraction of the supercritical water that extracts the light oil component and is withdrawn from the second phase is represented by Fw2, the withdrawing amounts of the effluent from the first phase and the effluent from the second phase are shown by the following expressions (3) and (4):

$$FW1 + Pitch = FW1 + FPitch \quad (3)$$

$$FW2 + Lt = FW2 + FLt \quad (4)$$

[0034]

When the volume of the first phase in the reactor 10 is

represented by V1, and the volume of the second phase therein is represented by V2, the residence time of the effluent from the first phase θpitch and the residence time of the effluent from the second phase θLt are shown by the following expressions (5) and (6):

$$\theta pitch = V1 / FW1 + Pitch = V1 / (FW1 + FPitch) \quad (5)$$

$$\theta Lt = V2 / FW2 + Lt = V2 / (FW2 + FLt) \quad (6)$$

[0035]

According to the expression (5), assuming that the volume of the first phase V1 is constant, the residence time of the effluent from the first phase θpitch can be controlled by adjusting the withdrawing amount of the effluent from the first phase FW1 + Pitch from the heavy oil component withdrawing line 140. In the apparatus for producing an upgraded oil of this embodiment, it has been confirmed from the results of the examples shown later that when the residence time θpitch is controlled to a range (3 minutes ≤ θpitch ≤ 95 minutes), the formation amount of coke in the heavy oil component can be suppressed to 0 to 20% by weight of the heavy oil component, and the kinematic viscosity at 350°C of the residual can be controlled to 3.0×10^{-5} m^2/s or less (30 cSt or less).

[0036]

The solubility of the supercritical water in the heavy oil component is constant under the condition with constant temperature and pressure, and thus when the flow rate of the heavy oil component FPitch that is withdrawn from the first phase is determined, the amount of the supercritical water FW1 that is dissolved in the heavy oil component. When the feeding amount of the supercritical water FWin is controlled under the condition, the amount of the supercritical water that is not dissolved in the heavy oil component, i.e., the amount of the supercritical water FW2 that forms the second phase, can be controlled. The amount of the supercritical water FW1 that is dissolved in the heavy oil component withdrawn at the flow rate FPitch may be determined, for example, by performing a preliminary experiment.

[0037]

From the relationship described above, when the volume of the second phase V2 is constant, FW2 in the expression (6) is controlled by controlling the feeding amount of the supercritical water FWin from the supercritical water feeding line 120, and thereby the residence time of the effluent from the second phase θLt can be controlled. In the apparatus for producing an upgraded oil of this embodiment, it has been confirmed from the results of the examples shown later that when θLt is controlled to a range (1 minute $\leq \theta Lt \leq$ 25 minutes),

the formation amount of gas due to excessive cracking can be suppressed to a range of from 0 to 5% by mass of the heavy oil, and the kinematic viscosity at 10°C of the sole light oil component or the synthetic crude oil obtained by mixing with the heavy oil component can be controlled to 5.0×10^{-3} m^2/s or less (5,000 cSt or less).

[0038]

Based on the concept described above, a flow rate controller 93 that controls the withdrawing amount of the effluent from the first phase FW1 + Pitch is provided on the heavy oil component withdrawing line 140, and the indicated value (b) of the flow rate controller 93 is output to a controlling part 9. The controlling part 9 calculates the residence time θpitch based on the expression (5), and controls the flow rate set value (e) of the flow rate controller 93 to control the opening of the flow rate controlling valve 142, thereby setting θpitch to the target value having been determined in advance. In this point of view, the flow rate controlling valve 142 corresponds to the first flow rate controlling unit.

[0039]

A flow rate controller 92 that controls the feeding amount of the supercritical water FWin (i.e., FW2) is provided on the supercritical water feeding line 120, and the indicated value (a) of the flow rate controller 92 is output to the

controlling part 9. The controlling part 9 calculates the residence time θLt based on the expression (6), and controls the flow rate set value (d) of the flow rate controller 92 to control the opening of a flow rate controlling valve 122, thereby setting θLt to the target value having been determined in advance.

[0040]

An interface level meter 94, such as a differential pressure type, an ultrasonic type or an X-ray type, as an interface detector of this embodiment is provided on the reactor 10, and outputs a signal (c) showing "high interface level" or "low interface level" to the controlling part 9 when the interface level between the first phase and the second phase in the reactor 10 is higher than or lower than the range having been determined in advance. The controlling part 9 controls the flow rate set value (f) of a flow rate controller 91 provided on the heavy oil feeding line 110 to control the feeding amount of the heavy oil FOin, thereby reverting the interface level to the set range, and thus the volume of the first phase V1 (i.e., the volume of the second phase V2) is maintained constant.

The pressure inside the reactor 10 is controlled, for example, by a pressure controller, which is not shown in the figure, provided on a light oil component line 310 of a high pressure separator 30 shown in Fig. 5 described later, by

controlling the withdrawing amount of the effluent from the second phase from the reactor 10 through regulation of the pressure controlling valve 131. In this point of view, the pressure controlling valve 131 corresponds to the second flow rate controlling unit.

[0041]

In the apparatus for producing an upgraded oil having the structure described above, the operation of controlling residence times θpitch and θLt is described. Assuming that the residence time of the effluent from the first phase θpitch in the first phase now becomes larger than the set value, the expression (5) shows that θpitch can be decreased and reverted to the set value by increasing the withdrawing amount of the effluent from the first phase FPitch. When FPitch is increased, however, the interface level is lowered, and a signal of "low interface level" is output from the interface level meter 94, which operates the flow rate controlling valve 112 to increase the feeding amount of the heavy oil FOin from the heavy oil feeding line 110.

[0042]

In the increment of the feeding amount of the heavy oil ΔFOin, "ΔFPitch" is distributed to the first phase, whereas "ΔFLt" is distributed to the second phase. This results in decrease of θLt according to the expression (6), but with respect to this change, θLt can be increased and reverted to

the set value by decreasing the feeding amount of the supercritical water FWin (i.e., FW2).

[0043]

On the other hand, assuming that the residence time of the effluent from the second phase θLt in the second phase now becomes larger than the set value, the expression (6) shows that θLt is decreased and reverted to the set value by increasing the feeding amount of the supercritical water FWin (i.e., FW2). Even when FWin is increased, for example, the withdrawing amount from the second phase FW2 + Lt is increased corresponding to the increment of FWin (FW2) to maintain the pressure inside the reactor 10, thereby retaining the interface between the first phase and the second phase to the constant level.

[0044]

In the example shown in Fig. 2, the interface level meter 94 is provided to measure actually the interface between the first and second phases, thereby making V1 and V2 constant, but the apparatus for producing an upgraded oil may not necessarily have the interface level meter 94. For example, such an operation may be employed that the yield ratios of the fraction lighter than VGO and the VR fraction corresponding to the kind of the heavy oil and the temperature and pressure conditions are comprehended in advance by a preliminary experiment or the like, the interface level in the reactor 10

is estimated from the values of FOin, FWin, FPitch, FLt, FW1 and FW2, V1 and V2 are maintained constant based on the estimated interface level, and the residence times θpitch and θLt are controlled based on the expressions (5) and (6).

[0045]

In the example shown in Fig. 2, V1 and V2 are maintained constant, and the residence times θpitch and θLt are controlled, but such an operation may be employed that θpitch and θLt are controlled while changing V1 and V2. For example, when the residence time of the effluent from the first phase θpitch in the first phase becomes larger than the set value, θpitch may be decreased and reverted to the set value by increasing the withdrawing amount of the effluent from the first phase FPitch and decreasing the volume of the first phase V1, according to the expression (5). This results in increase of the volume of the second phase V2, which affects the residence time of the effluent from the second phase θLt, but the feeding amount of the supercritical water FWin (i.e., FW2) may be increased to cancel the increment of the volume V2, thereby reverting θLt to the set value.

[0046]

In the examples described above, the residence time of the effluent from the first phase θpitch in the first phase is controlled with the withdrawing amount of the first fluid FPitch, and the residence time of the effluent from the second

phase θLt in the second phase is controlled with the feeding amount of the supercritical water FWin, but the examples do not deny such an operation that the residence times are controlled with other operational variables shown in the expressions (5) and (6), for example, the feeding amount of the heavy oil FOin and the withdrawing amount of the effluent from the second phase FW2 + Ltout.

[0047]

Mixing Part

Fig. 3 shows a structural example of the mixing part 3, which contains a mixing tank 21, into which the light oil component and a part or the whole of the heavy oil component obtained in the reactor 1 flow, and an agitator 22 that agitates the fluid in the mixing tank 21. The fluid mixed in the mixing tank 21 is sent as a synthetic crude oil to pipelines or the like. As shown in Fig. 4, the mixing part 3 may be constituted by an inline mixer 23. The inline mixer 23 may be provided, for example, on the downstream side of the merging section of the pipe, in which the light oil component flows, and the pipe, in which a part or the whole of the heavy oil component flows.

[0048]

With respect to the mixing ratio of the heavy oil component mixed into the light oil component in the mixing part 2, such a case may be considered that the mixing ratio of the heavy oil component is increased within such a range that the

synthetic crude oil satisfies the product standard having been set therefor in advance, for example, the specific gravity (e.g., the API (American Petroleum Institute) specific gravity and density) and the viscosity. The whole amount of the heavy oil component obtained from the reactor 1 may be mixed into the light oil component unless the product standard is violated.

[0049]

The mixing amounts of the light oil component and the heavy oil component are controlled to such a range that the compatibility of the synthetic crude oil after mixing is ensured, or in other words, to such a range that the synthetic crude oil after mixing is not separated again into the heavy and light oil components. The mixing ratio of the heavy oil component in the synthetic crude oil may be determined in consideration of the yield ratio of the heavy oil component from the reactor 10, and the like, in addition to the product standard and the compatibility of the synthetic oil, but is not limited to a specific ratio.

[0050]

First Structural Example

A specific structural example of the apparatus for producing an upgraded oil having been described above is described with reference to Fig. 5. The apparatus for producing an upgraded oil upgrades a heavy oil by making the

heavy oil in contact with supercritical water, and contains: a reactor 10 (reactor) that separates the heavy oil into a heavy oil component and a light oil component; a high-pressure separator 30 that performs oil-water separation of the mixed fluid of the light oil component and the supercritical water flowing from the reactor 10, under a pressure condition that is equivalent to the pressure inside the reactor 10; a low-pressure separator 40 that performs oil-water separation of the mixed fluid of the light oil component and water flowing from the high-pressure separator 30, under a pressure condition lower than the high-pressure separator 30; a flash drum 50 that performs oil-water separation of the mixed fluid of the heavy oil component and the supercritical water flowing from the reactor 10, under a pressure condition lower than the reactor 10, and separates a light oil fraction contained in the heavy oil component therefrom; a separator 70 that performs oil-water separation of the mixed fluid of water and the light oil fraction flash-distilled in the flash drum 50; and a recycled water tank 60 that that recycles water after the oil-water separation.

[0051]

The reactor 10 is a pressure resistant vessel having the structure having been described with reference to Fig. 2 in the form, for example, of a tower, and to a side wall at an upper part of the reaction vessel, for example, a heavy oil

feeding line 110 for receiving a heavy oil from a heavy oil supply source 11 is connected. The heavy oil supply source 11 is constituted, for example, by a tank that stores the heavy oil.

[0052]

The heavy oil feeding line 110 has installed thereon a heavy oil feeding pump 111 that feeds the heavy oil received from the heavy oil supply source 11 under an increased pressure, for example, of from 25 to 30 MPa, that is higher than 22.1 MPa, which is the critical pressure of water, to the reactor 10, and a heater 113 constituted, for example, by a heating furnace, that heats the heavy oil fed to the reactor 10 to a temperature, for example, of from 300 to 450°C. The heavy oil is fed at a temperature lower than the temperature inside the reactor 10 (for example, from 374 to 500°C) for preventing polycondensation in the heavy oil feeding line 110 and the heater 113. The heavy oil feeding line 110, the heavy oil feeding pump 111, the flow rate controlling valve 112, the heater 113 and the like correspond to the heavy oil feeding part of the embodiment.

[0053]

To a side wall at a lower part of the reaction vessel, a supercritical water feeding line 120 for making water received from a water supply source 12, which is constituted, for example, by a water storage tank, in a supercritical state

and feeding the supercritical water to the reactor 10 is connected. The supercritical water feeding line 120 has installed thereon a supercritical water feeding pump 121 that pressurizes the water received from the water supply source 12 to a pressure, for example, of from 25 to 30 MPa, that is higher than the critical pressure of water (22.1 MPa), and feeds the supercritical water to the reactor 10, the flow rate controlling valve 122 that controls the flow rate of the supercritical water, and a heater 123 constituted, for example, by a heating furnace, that heats the supercritical water fed to the reactor 10 to a temperature higher than the critical temperature thereof (374°C), for example, of from 450 to 600°C.

As having been described above, the heavy oil fed from the heavy oil feeding line 110 is fed at a temperature lower than the temperature inside the reactor 10 for preventing polycondensation, and therefore, the supercritical water fed from the supercritical water feeding line 120 is fed at a temperature higher than the temperature inside the reactor 10, thereby feeding heat that is necessary for thermal cracking of the heavy oil. The supercritical water feeding line 120, the supercritical water feeding pump 121, the flow rate controlling valve 122, the heater 123 and the like correspond to the supercritical water feeding part of the embodiment.

[0054]

To a tower top of the reactor 10, for example, a light

oil component withdrawing line 130 for withdrawing a mixed fluid formed through extraction of the light oil component obtained by cracking the heavy oil in the reactor 10 into the supercritical water, from the first phase is connected. The light oil component withdrawing line 130 has installed thereon a cooling device 132, which is constituted, for example, by a heat exchanger, that cools the mixed fluid flowing in the light oil component withdrawing line 130 to a temperature, for example, of from 200 to 374°C, that is lower than the critical temperature of water.

[0055]

On the downstream side of the light oil component withdrawing line 130, a high-pressure separator 30 that separates the mixed fluid cooled with the cooling device 132 into a light oil component (provided that the light oil component contains water) and water under a pressure that is substantially equivalent to the pressure inside the reactor 10 is provided. To an upper part of the high-pressure separator 30, a light oil component line 310 that withdraws the light oil component and feeds to a low-pressure separator 40 is connected. The light oil component line 310 has installed thereon a cooling device 312, which is constituted, for example, a heat exchanger, that cools the light oil component to a temperature of approximately from 40 to 100°C, and a pressure reducing valve 311 that reduces the pressure

of the light oil component flowing in the line 310, for example, to a pressure of approximately from 0.2 to 1.0 MPa, which is higher than ordinary pressure. The pressure reducing valve 311 also has a function of the pressure controlling valve 131 shown in Fig. 2.

[0056]

At the bottom of the high-pressure separator 30, a high-pressure separated water line 320 that withdraws water having been separated from the light oil component under a condition of a pressure of approximately from 25 to 30 MPa and a temperature of approximately from 200 to 374°C is provided. The high-pressure separated water line 320 is connected to a recycle water line 610 described later, whereby the separated water from the high-pressure separator 30 can be fed again to the reactor 10. A device 321 installed on the high-pressure separated water line 320 is a high-pressure separated water recycling pump that feeds the separated water from the high-pressure separator 30.

[0057]

A low-pressure separator 40 provided on the downstream side of the light oil component line 310 is described. The low-pressure separator 40 separates the light oil component containing water flowing from the high-pressure separator 30 again into the light oil component and water under a condition of a pressure of approximately from 0.2 to 1.0 MPa and a

temperature of approximately from 40 to 100°C. A line 420 is a synthetic crude oil line that delivers the light oil component having been separated from water as a synthetic crude oil to a synthetic crude oil tank 82.

[0058]

To a bottom of the low-pressure separator 40, a low-pressure separated water recycling line 430 is connected, and the low-pressure separated water recycling line 430 withdraws water separated from the light oil component and feeds the water to the recycled water tank 60 for recycling as supercritical water. From the low-pressure separated water recycling line 430, a wastewater line 440 that withdraws a part of the recycled water toward a wastewater treating unit 83 is branched, and the liquid amount fed to the wastewater treating unit 83 is controlled, thereby controlling the concentration of the oil component and the concentration of salts in the recycled water circulating in the apparatus for producing the upgraded oil to the prescribed values or less. In the figure, numeral 410 denotes a off gas line that feeds gas evaporated from the light oil component to a off gas treating unit 81. The high-pressure separator 30 and the low-pressure separator 40 correspond to the second separating part of the embodiment.

[0059]

Apart from the process flow of the tower top system of the reactor 10 having been described above, for example, at

a tower bottom of the reactor 10, a heavy oil component withdrawing line 140 that withdraws a mixed fluid of the heavy oil component having been cracked in the reactor 10 that is not extracted to the supercritical water and the supercritical water dissolved in the heavy oil component, from the second phase is connected. The heavy oil component withdrawing line 140 has installed thereon a cooling device 141, which is constituted, for example, by a heat exchanger, that cools the mixed fluid flowing in the heavy oil component withdrawing line 140 to a temperature of approximately from 200 to 350°C, and a flow controlling valve 142 that controls the withdrawing amount of the mixed fluid from the bottom of the reactor 10 and reduces the pressure of the mixed fluid flowing in the heavy oil component withdrawing line 140 to a pressure of approximately from 0.2 to 1.0 MPa, which is higher than ordinary pressure.

[0060]

The flow rate controlling valve 142 is connected to the flash drum 50, and the flash drum 50 performs flash distillation under a pressure condition of approximately from 0.1 to 8 MPa and a temperature condition of approximately from 250 to 430°C, thereby performing a function of a flash part of separating the heavy oil component from water and the light oil component dissolved in the heavy oil component. The heavy oil component separated from the light oil component in the reactor 10

partially contains a fraction corresponding to the light oil component, and the light oil fraction is recovered to increase the production amount of the synthetic crude oil. A line 510 connected to the flash drum 50 is a flash fluid line 510 that feeds the mixed fluid of the light oil fraction and water separated from the heavy oil component in the flash drum 50 to a separator 70 on the downstream side, and has installed thereon a cooling device 511, which is constituted, for example, by a heat exchanger, that cools the mixed fluid of the light oil fraction and water to a temperature of approximately from 40 to 100°C. A line 520 is a residual oil line that withdraws the heavy oil component separated from water as a residual oil for a boiler fuel to a residual oil tank 84.

[0061]

From the residual oil line 520, a synthetic crude oil mixing line 530 that feeds the whole amount or a part of the heavy oil component withdrawn from the flash drum 50 to the synthetic crude oil tank 82 after mixing into the light oil component withdrawn from the low-pressure separator 40 is branched. An example may be shown, in which as shown in Fig. 5, the synthetic crude oil mixing line 530 is connected to the synthetic crude oil line 420 from the low-pressure separator 40, and an inline mixer 23 shown in Fig. 4 is provided on the downstream side of the connected part to mix the heavy oil component into the light oil component, thereby producing a

synthetic crude oil. In this case, the merging section of the synthetic crude oil line 420 and the synthetic crude oil mixing line 530 corresponds to the mixing part 2 shown in Fig. 1. The heavy oil component is mixed into the light oil component, thereby enhancing the yield of the synthetic crude oil having higher value than a boiler fuel.

[0062]

On the downstream side of the flash fluid line 510, a separator 70 as the first separating part that separates the fluid separated from the heavy oil component by flash distillation into the light oil fraction and water is provided. At an upper part of the separator 70, a light oil fraction line 710 that withdraws the light oil fraction is provided, and the light oil fraction line 710 is connected to the synthetic crude oil line 420 that delivers the light oil component from the low-pressure separator 40 described above. According to the structure, the light oil fraction recovered from the heavy oil component is mixed into the light oil component as a raw material of the synthetic crude oil. In this point of view, the merging section of the light oil fraction line 710 and the synthetic crude oil line 420 corresponds to the light oil fraction mixing part of the example. On the downstream side of the separator 70, a drum separated water line 720 that recycles water separated from the light oil fraction in the separator 70 toward the separated water recycling line 430 is

connected.

[0063]

Thus, flash distillation is performed in the flash drum 50 to separate the heavy oil component from water and the light oil fraction dissolved in the heavy oil component, and then the light oil fraction is mixed as a raw material of the synthetic crude oil into the light oil component on the synthetic crude oil line 420, thereby facilitating dehydration of the heavy oil component, as compared to the case of mixing without flash distillation.

[0064]

Furthermore, water and the light oil fraction, which have a large difference in specific gravity, are subjected to oil-water separation in the high-pressure separator 30, thereby facilitating dehydration with a large difference in specific gravity, as compared to the case where oil-water separation is not performed in the high-pressure separator 30, and oil-water separation is performed after mixing the light oil component recovered from the heavy oil component.

[0065]

The recycle system of water for the supercritical water is described. The recycled water tank 60 provided on the downstream side of the low-pressure separated water recycling line 430 receives water separated from the light oil component in the low-pressure separator 40 and water separated from the

light oil fraction in the separator 70. Water collected in the recycled water tank 60 is fed again to the supercritical water feeding line 120. A line 610 is a recycled water line that connects the recycled water tank 60 and the supercritical water feeding line 120, and a device 611 is a recycled water pump that feeds water delivered from the recycled water tank 60 to the supercritical water feeding line 120 after pressurizing to a pressure higher than the critical pressure of water (22.1 MPa), for example, from 22.1 to 40 MPa. As described above, the high-pressure separated water line 320 that recycles water separated from the high-pressure separator 30 is merged to the recycled water line 610. Water used as the supercritical water is recycled to reduce the amount of fresh water used, which facilitates procurement of water necessary for upgrading a heavy oil, and reduces the environmental load.

[0066]

Second Structural Example

An apparatus for producing an upgraded oil shown in Fig. 6 is different in such a point that the heavy oil component in the state of a mixed fluid with the supercritical water withdrawn from the first phase is mixed into the light oil component in the state of a mixed fluid with the supercritical water withdrawn from the second phase, from the first structural example, in which the heavy oil component and the

light oil component are mixed after separating water. In this example, a heavy oil component mixing line 150 is branched from the heavy oil component withdrawing line 140, and the heavy oil component mixing line 150 is merged to the light oil component withdrawing line 130, thereby constituting the mixing part 2.

[0067]

The following advantages may be obtained by the apparatus for producing upgraded oil according to the embodiment described above. A heavy oil is thermally cracked to a heavy oil component and a light oil component by making the heavy oil in contact with supercritical water, and the heavy oil component is mixed into the light oil component to produce an upgraded oil, whereby an upgraded oil can be obtained with a high yield ratio as compared to the case where the heavy oil component is not mixed.

[0068]

A heavy oil is cracked in such a range that formation of coke in the heavy oil component can be suppressed to approximately from 0 to 20% by weight, whereby adhesion and accumulation amount of coke to the inner wall of the reactor 10 and the inner walls of pipes of the heavy oil component system can be reduced. For example, there is no necessity of switch of coke drums due to accumulation of coke, such as a delayed coker having plural coke drums provided, or removal of

accumulated coke, and thus a continuous operation for a prolonged period of time can be performed with a simple structure.

[0069]

Examples of the structure of the mixing part 2 is not limited to the examples where the heavy oil component is continuously mixed into the light oil component after separating from water, by connecting the synthetic crude oil mixing line 530 to the synthetic crude oil line 420 (Fig. 5), or the example where the heavy oil component is continuously mixed into the light oil component in the state of a mixed fluid with the supercritical water, by connecting the heavy oil component mixing line 150 to the light oil component withdrawing line 130 (Fig. 6). For example, such a structure may be employed that the synthetic crude oil mixing line 530 shown in Fig. 5 is not provided, but the while amount of the heavy oil component is delivered from the residual oil line 520 to the residual oil tank 84, and the heavy oil component is delivered from the residual oil line 520 to the mixing tank 21 shown in Fig. 3 and mixed into the light oil component.

[0070]

In the case where the light oil fraction is not recovered from the heavy oil component, the separator 70 provided in Figs. 5 to 6 may be omitted. In this case, the flash drum 50 may be controlled to a condition that is suitable for flashing only

water from the heavy oil component, for example, a pressure condition of approximately from 0.4 to 1.0 MPa and a temperature condition of approximately from 200 to 350°C. Water thus recovered from the flash drum 50 is fed directly to the recycled water tank.

[0071]

In the case where the heavy oil component is mixed before performing oil-water separation in the separator 40a on the side of the light oil component as in the structural example shown in Fig. 6, the flash drum 50 may be omitted. For example, in the case where the residual oil is used as a boiler fuel in a plant in the vicinity of the apparatus for producing an upgraded oil, the residual oil in the state where water is dispersed therein is used as a boiler fuel without the pressure reduction operation of the effluent from the first phase, thereby further decreasing the viscosity of the residual oil for facilitating the handling of the residual oil. Furthermore, the vaporization upon using the residual oil as a boiler fuel is accelerated by the effect of water dispersed in the residual oil, thereby enhancing the combustion quality in the boiler.

[0072]

In the embodiments described above, the case where an extra heavy oil, such as oil sand bitumen and Orinoco tar, is processed as the heavy oil to be upgraded with the apparatus

for producing an upgraded oil, but the heavy oil that is capable of being processed with the apparatus for producing an upgraded oil is not limited to a crude oil. For example, cases where a residual oil of normal pressure distillation or a residual oil of reduced pressure distillation is upgraded are encompassed by the technical scope of the invention.

[Examples]

[0073]

Experiment 1

A test apparatus was produced according to the aforementioned apparatus for producing an upgraded oil as a model, and an upgrading experiment of a heavy oil was performed.

[0074]

A. Experiment Conditions

In this apparatus, the residence time of the effluent from the first phase θPitch was controlled by the withdrawing amount of the residual oil FPitch from the reactor 10, and the residence time of the effluent from the second phase θLt was controlled by the feeding amount of the supercritical water FWin. The heavy oil used was Canadian oil sand bitumen having the properties shown in Table 1.

Table 1

Density (g/cm^3)	1.012
Kinematic viscosity at 40°C (m^2/s)	1.7×10^{-2}

[0075]

Example 1

The experiment was performed under the following conditions.

reaction temperature in reactor 10: 430°C

reaction pressure in reactor 10: 25 MPa

water/oil weight ratio: 1.0

residence time of effluent from the first phase θPitch: 95 minutes

residence time of effluent from the second phase θLt: 2.3 minutes

Example 2

The experiment was performed under the same conditions as in Example 1 except for the following.

reaction temperature in reactor 10: 450°C

residence time of effluent from the first phase θPitch: 4.9 minutes

residence time of effluent from the second phase θLt: 11 minutes

Example 3

The experiment was performed under the same conditions as in Example 1 except for the following.

water/oil weight ratio: 0.5

residence time of effluent from the first phase θPitch: 32 minutes

residence time of effluent from the second phase θLt: 25 minutes

Example 4

The experiment was performed under the same conditions as in Example 1 except for the following.

residence time of effluent from the first phase θPitch: 67 minutes

residence time of effluent from the second phase θLt: 1.8 minutes

Comparative Example 1

The experiment was performed under the same conditions as in Example 1 except for the following.

residence time of effluent from the first phase θPitch: 105 minutes

residence time of effluent from the second phase θLt: 1.1 minutes

The experiment conditions of Examples and Comparative Example are shown in Table 2.

Table 2

	Example 1	Example 2	Example 3	Example 4	Comparative Example 1
Temperature of reactor (°C)	430	450	430	430	430
Pressure of reactor (MPa)	25	25	25	25	25
Water/oil ratio	1.0	1.0	0.5	1.0	1.0
Residence time of effluent from the first phase θPitch (min)	95	4.9	32	67	105
Residence time of effluent from the second phase θLt (min)	2.3	11	25	1.8	1.1

[0076]

B. Experiment Results

Table 3 shows the yields of the gas, the synthetic crude oil (light oil component) and the residual oil (heavy oil component) in Examples and Comparative Examples. Table 4 shows the properties of the synthetic oils, and Table 5 shows the properties of the residual oils. In this experiment, the heavy oil component was not mixed into the light oil component.

Table 3

	Example 1	Example 2	Example 3	Example 4	Comparative Example 1
Yield of gas (% by weight)	4	2	3	1	-
Yield of synthetic crude oil (% by weight)	74	60	63	63	-
Yield of residual oil (% by weight)	22	38	34	36	formation of coke

Table 4

	Example 1	Example 2	Example 3	Example 4	Comparative Example 1
Density (g/cm^3)	0.916	0.915	0.911	0.918	-
Kinematic viscosity at 10°C (m^2/s)	2.6×10^{-5}	2.0×10^{-5}	1.6×10^{-5}	2.8×10^{-5}	-

Table 5

	Example 1	Example 2	Example 3	Example 4	Comparative Example 1
Density (g/cm^3)	1.173	1.100	1.116	1.101	-
Kinematic viscosity at 310°C (m^2/s)	1.8×10^{-5}	1.2×10^{-5}	1.2×10^{-5}	1.4×10^{-5}	-

[0077]

The same oil sand bitumen as used in Example 1 was treated by the visbreaker process and the delayed coker process. The results of comparison of the yield ratios of each fraction thus obtained and the yield ratios of each fraction obtained in Examples 1 and 2 is shown in Table 6. For Examples 1 and 2, the yield ratios of the synthetic crude oil and the residual wafer are synthesized and converted to the VGO fraction having

a boiling point of 540°C or less and the VR fraction having a boiling point exceeding 540°C, and thus they may not necessarily agree with the yield ratios shown in Table 3.

Table 6

		Example 1	Example 2	Delayed coker	visbreaker
Gas (wt%)		3	2	7	2
Liquid	VGO fraction (wt%)	74	67	75	64
	VR fraction (wt%)	22	31	0	32
Coke (wt%)		0	0	19	2

[0078]

According to the results of Experiment 1, when the residence time of the effluent from the first phase (which may be hereinafter referred to as a first residence time) θPitch is increased in the order of Example 2 (θPitch: 4.9 minutes), Example 3 (θPitch: 32 minutes) and Example 1 (θPitch: 95 minutes), the yield of the residual oil is lowered, whereas the yield of the synthetic crude oil is increased. Formation of coke (coking) is observed in Comparative Example 1 where θPitch is 105 minutes. It is not clear why the yield of the residual oil in Example 4 (θPitch: 67 minutes) where the first residence time θPitch is longer than Example 3 is larger than Example 3, but the yield of the synthetic crude oil in Example 4 is equivalent to Example 3, and it is considered that this is because of the influence of fluctuation errors.

[0079]

With respect to the yield of gas, there is a tendency that the yield of gas is increased when the residence time of the effluent from the second phase (which may be hereinafter referred to as a second residence time) θLt is increased in the order of Example 4 (θLt: 1.8 minutes), Example 2 (11 minutes) and Example 3 (25 minutes), except for Example 1 (2.3 minutes) where the largest yield of gas is obtained. It is not clear why the yield of gas becomes maximum, 4% by weight, in Example 1 where the second residence time θLt is the next shortest, and it is considered that this is also because of the influence of fluctuation errors.

[0080]

According to the measurement results of kinematic viscosity of the synthetic crude oil shown in Table 4, synthetic crude oils with kinematic viscosity that has no practical problem are obtained in all Examples, i.e., the maximum thereof is 2.8×10^{-5} m^2/s (28 cSt) at 10°C (standard value: 5.0×10^{-3} m^2/s (5,000 cSt). There is a tendency that the kinematic viscosity of the synthetic crude oil is decreased when the second residence time θLt is increased in the order of Example 4 (θLt: 1.8 minutes), Example 1 (2.3 minutes), Example 2 (11 minutes) and Example 3 (25 minutes). It is considered that this is because cracking of the light oil component proceeds when the second residence time is increased. This is also

confirmed by the fact that the density of the synthetic crude oil is decreased when the second residence time is increased.

[0081]

According to the measurement results of kinematic viscosity of the residual oil shown in Table 5, residual oils with kinematic viscosity that has no practical problem are obtained in all Examples, i.e., the maximum thereof is 1.8 × 10^{-5} m^2/s (18 cSt) at 310°C. When the residual oil is heated to 350°C, the kinematic viscosity is further decreased. There is a tendency that the kinematic viscosity of the residual oil is increased when the first residence time θPitch is increased in the order of Example 2 (θPitch: 4.9 minutes), Example 3 (32 minutes), Example 4 (67 minutes) and Example 1 (95 minutes). It is considered that this is because of the results of the fact that polymerization of the heavy oil component proceeds against the cage effect of the supercritical water dissolved in the heavy oil component when the first residence time is increased. This is also confirmed by the fact that the density of the residual oil is increased when the first residence time is increased.

[0082]

Gathering the results in Examples 1 to 4 and Comparative Example 1, it is understood that with oil sand bitumen used as the heavy oil as a raw material, when the first residence time θPitch is in a range of approximately from 3 to 95 minutes,

a residual oil that has good handleability is obtained by decreasing the kinematic viscosity thereof at 310°C to 1.8 × 10^{-5} m^2/s (18 cSt) or less while suppressing formation of coke. It is also understood that when the second residence time θLt is in a range of approximately from 1 to 25 minutes, a synthetic crude oil having a kinematic viscosity of 2.8 × 10^{-5} m^2/s (28 cSt) or less at 10°C is obtained while suppressing the formation of gas to approximately 4% by weight.

[0083]

According to the results shown in Table 6, formation of coke is suppressed, whereas the yield ratio of a VGO fraction is higher than the visbreaker process, and Example 1 provides a yield ratio of a VGO fraction that is equivalent to the delayed coker process. It is understood from the results that the thermal cracking of a heavy oil by utilizing supercritical water is a thermal cracking process that is capable of providing a VGO fraction (light oil component) at a high yield ratio while suppressing formation of coke and gas, by controlling the first and second residence times suitably.

[0084]

Experiment 2

An inspection window for observing the interior was provided on the reactor 1 of the same experiment apparatus as in Example 1, and it was confirmed that the fluid in the vessel was separated into the first phase and the second phase to form

an interface. As a result of visual observation, it was confirmed that there are the first phase containing a heavy oil component and supercritical water dissolved in the heavy oil component, and the second phase containing supercritical water and a light oil component extracted to the supercritical water, at the lower part of the reactor 1.

[0085]

Experiment 3

An experiment where a heavy oil component and a light oil component obtained by an upgrading experiment of a heavy oil are mixed to produce a synthetic crude oil was performed.

[0086]

A. Experiment Conditions

Oil sand bitumen having the properties shown in Table 1 was processed with the same experiment apparatus as in Experiment 1 while changing the residence time of the effluent from the first phase θPitch and the residence time of the effluent from the second phase θLt. Based on the properties of the light oil component and the heavy oil component thus obtained, the amount of the heavy oil component that was able to be mixed into the light oil component was investigated. In the reactor 10, the reaction temperature was 430°C, the reaction pressure was 25 MPa, and the water/oil ratio was 1, which were constant.

Example 3-1

The amount of the heavy oil component that was able to be mixed into the light oil component was determined to provide an API specific gravity of the synthetic crude oil of 21.0° while the residence time of the effluent from the first phase θPitch was 9.7 minutes, and the residence time of the effluent from the second phase θLt was 6.7 minutes.

Example 3-2

The same experiment as in Example 3-1 except that the residence time of the effluent from the first phase θPitch was 25.7 minutes, and the residence time of the effluent from the second phase θLt was 7.7 minutes.

Example 3-3

The same experiment as in Example 3-2 except that the residence time of the effluent from the first phase θPitch was 37.7 minutes, and the residence time of the effluent from the second phase θLt was 4.0 minutes.

The experiment conditions of Examples are shown in Table 7.

Table 7

	Example 3-1	Example 3-2	Example 3-3
Raw material oil	oil sand bitumen		
Reaction temperature (°C)	430		
Reaction pressure (MPa)	25		
Residence time of effluent from the first phase (min)	9.7	25.7	37.7
Residence time of effluent from the second phase (min)	6.7	7.7	4.0

[0087]

B. Experiment Results

The yields of the light oil component, the heavy oil component and the gas, and the density and the API specific gravity of the light oil component and the heavy oil component, which are obtained in the experiments of Examples 3-1 to 3-3 are shown in Table 8. The mixing ratios of the light oil component and the heavy oil component, and the yield of the synthetic crude oil when the product standard of the synthetic crude oil is set to an API specific gravity of 21.0 are shown in Table 9.

[0088]

Table 8

		Example 3-1	Example 3-2	Example 3-3
Light oil component (% by weight)		38.5	43.3	59.8
Heavy oil component (% by weight)		61.5	55.2	38.5
Gas (% by weight)		0.0	1.5	1.7
Density	Light oil component (g/cc)	0.925	0.924	0.910
	Heavy oil component (g/cc)	1.069	1.072	1.130
API specific gravity	Light oil component (°)	21.5	21.6	24.0
	Heavy oil component (°)	0.9	0.5	-6.3

Table 9

	Example 3-1	Example 3-2	Example 3-3
Density (g/cc)	0.928		
API specific gravity (°)	21		
Mixing ratio of light oil component (% by weight)	98.0	97.4	91.9
Mixing ratio of heavy oil component (% by weight)	2.0	26	8.1
Yield of synthetic crude oil (% by weight)	39.3	44.5	65.1

[0089]

According to the experiment results shown in Table 8, there is a tendency that when the residence time of the effluent from the first phase θPitch is increased, the yield of the light oil component is increased, and the property thereof is lightened (i.e., the density is decreased, and the API specific gravity is increased). On the other hand, when the residence time θPitch is increased, the yield of the heavy oil component is decreased, and the property thereof becomes heavy (i.e., the density is increased, and the API specific gravity is decreased. It is considered that this is because when the residence time θPitch is increased, thermal cracking of the heavy oil in the first phase proceeds to increase the yield of the light oil component, whereas a fraction that is hard to be thermally cracked remains to make the heavy oil component heavier.

[0090]

An investigation was performed for producing a synthetic

crude oil by mixing the light oil component and the heavy oil component obtained in Examples 3-1 to 3-3.

In Example 3-1, the yield of the synthetic crude oil was 39.3% by weight with a mixing ratio of the heavy oil component of 2.0% by weight in the synthetic crude oil. This shows that the yield of the synthetic crude oil can be increased by 0.8% by weight as compared to the yield of the light oil component shown in Table 7 (38.5% by weight). In Example 3-2, the yield of the synthetic crude oil was 44.5% by weight with a mixing ratio of the heavy oil component of 2.6% by weight in the synthetic crude oil. This shows that the yield of the synthetic crude oil can be increased by 1.2% by weight as compared to the yield of the light oil component shown in Table 7 (43.3% by weight). In Example 3-3, the yield of the synthetic crude oil was 65.1% by weight with a mixing ratio of the heavy oil component of 8.1% by weight in the synthetic crude oil. This shows that the yield of the synthetic crude oil can be increased by 5.3% by weight as compared to the yield of the light oil component shown in Table 7 (59.8% by weight). The synthetic crude oils obtained in Examples 3-1 to 3-3 had no problem in compatibility, and thus it was confirmed that a synthetic crude oil (upgraded oil) was able to be produced by thermal cracking of a heavy oil into a heavy oil component and a light oil component by making the heavy oil into contact with supercritical water, and then mixing the heavy oil component

into the light oil component.

[Description of the Reference Numerals and Signs]

[0091]

10 reactor

110 heavy oil feeding line

112 flow rate controlling valve

120 supercritical water feeding line

122 flow rate controlling valve

130 light oil component withdrawing line

131 pressure controlling valve

140 heavy oil component withdrawing line

142 flow rate controlling valve

2 mixing part

30 high-pressure separator

40 low-pressure separator

50 flash drum

60 recycled water tank

70 separator

9 controlling part

[Designation of Document]

Claims

[Claim 1]

A method for producing an upgraded oil, comprising:

a step of feeding a heavy oil to a reactor;

a step of feeding supercritical water to the reactor;

a step of thermal cracking of the heavy oil by making the heavy oil and the supercritical water in contact with each other while maintaining conditions in the reactor to a temperature and a pressure that are higher than a critical point of water;

a step of forming at a lower part of the reactor a first phase containing a heavy oil component obtained by thermal cracking of the heavy oil and the supercritical water dissolved in the heavy oil component, and forming at an upper part of the reactor a second phase containing the supercritical water and a light oil component extracted by the supercritical water;

a step of withdrawing a effluent from the first phase at the lower part of the reactor, for suppressing formation of coke in the heavy oil component;

a step of withdrawing a effluent from the second phase at the upper part of the reactor, for suppressing formation of gas in the light oil component; and

a step of providing an upgraded oil by mixing the heavy oil component of the effluent from the first phase into the

light oil component of the effluent from the second phase.

[Claim 2]

The method for producing an upgraded oil according to claim 1, wherein

the method comprises:

a step of flash distillation of the effluent from the first phase to separate into a mixed vapor of a light oil fraction contained in the heavy oil component of the first phase and water, and a remaining heavy oil component;

a step of separating the mixed vapor into the light oil fraction and water by cooling the mixed vapor; and

a step of mixing the light oil fraction into the light oil component in the effluent from the second phase, and

in the step of providing an upgraded oil, the heavy oil component produced by flash distillation is mixed into the light oil component.

[Claim 3]

The method for producing an upgraded oil according to claim 1 or 2, wherein

the method comprises:

a step of separating the effluent from the second phase into the light oil component and water, and

in the step of providing an upgraded oil, the heavy oil component is mixed into the light oil component having been separated from water.

[Claim 4]

The method for producing an upgraded oil according to any one of claims 1 to 3, wherein an amount of the heavy oil component that is mixed into the light oil component is in a range that satisfies a standard of specific gravity or viscosity that is prescribed to the upgraded oil.

[Claim 5]

The method for producing an upgraded oil according to any one of claims 1 to 4, wherein the method comprises a step of controlling a withdrawing amount of the effluent from the first phase to such an amount that a residence time of the effluent from the first phase is one of:

(i) a residence time in a range of from 3 to 95 minutes,

(ii) a residence time that proceeds thermal cracking of the heavy oil in such a range that a formation amount of coke is from 0 to 20% by weight of the heavy oil component, and

(iii) a residence time that proceeds thermal cracking of the heavy oil to such an extent that a kinematic viscosity of the heavy oil component at 350°C is 3.0×10^{-5} m^2/s or less.

[Claim 6]

The method for producing an upgraded oil according to any one of claims 1 to 5, wherein the method comprises a step of controlling a feeding amount of the supercritical water to the reactor to such an amount that the second residence time

of the effluent from the second phase is one of:

(i) the residence time of the effluent from the second phase in a range of from 1 to 25 minutes, for suppressing excessive cracking of the light oil component,

(ii) a residence time that proceeds thermal cracking of the heavy oil in such a range that a formation amount of gas due to excessive cracking is from 0 to 5% by weight of the heavy oil, and

(iii) a residence time that proceeds thermal cracking of the heavy oil to such an extent that a kinematic viscosity of the light oil component at 10°C is 5.0×10^{-3} m^2/s or less.

[Claim 7]

An apparatus for producing an upgraded oil, comprising:

a reactor that is maintained to a temperature and a pressure that are higher than a critical point of water, in which while proceeding thermal cracking of a heavy oil by making the heavy oil and supercritical water in contact with each other, a first phase containing a heavy oil component obtained by thermal cracking of the heavy oil and the supercritical water dissolved in the heavy oil component is formed at a lower part thereof, and a second phase containing the supercritical water and a light oil component extracted by the supercritical water is formed at an upper part thereof;

a first flow rate controlling unit that withdraws a effluent from the first phase containing the heavy oil

component and the supercritical water dissolved in the heavy oil component in the first phase at the lower part of the reactor, for suppressing formation of coke in the heavy oil component;

a second flow rate controlling unit that withdraws a effluent from the second phase at the upper part of the reactor, for suppressing formation of gas in the light oil component; and

a mixing part that mixes the heavy oil component of the effluent from the first phase into the light oil component of the effluent from the second phase withdrawn from the upper part of the reactor, thereby providing an upgraded oil.

[Claim 8]

The apparatus for producing an upgraded oil according to claim 7, wherein

the apparatus comprises:

a flashing part that conduct flash distillation of the effluent from the first phase to separate into a mixed vapor of a light oil fraction contained in the heavy oil component of the first phase and water, and a remaining heavy oil component;

a first separating part that separates the mixed vapor into the light oil fraction and water by cooling the mixed vapor; and

a light oil fraction mixing part that mixes the light oil fraction into the light oil component in the effluent from

the second phase, and

in the mixing part, the heavy oil component having been obtained by flash distillation is mixed into the light oil component.

[Claim 9]

The apparatus for producing an upgraded oil according to claim 7 or 8, wherein

The apparatus comprises:

a second separating part that separates the effluent from the second phase into the light oil component and water, and

in the mixing part, the heavy oil component is mixed into the light oil component having been separated from water.

[Claim 10]

The apparatus for producing an upgraded oil according to any one of claims 7 to 9, wherein an amount of the heavy oil component that is mixed into the light oil component is in a range that satisfies a standard of specific gravity or viscosity that is prescribed to the upgraded oil.

[Claim 11]

The apparatus for producing an upgraded oil according to any one of claims 7 to 10, wherein the apparatus comprises a controlling part that controls a withdrawing amount of the effluent from the first phase to such an amount that a residence time of the effluent from the first phase is one of:

(i) a residence time in a range of from 3 to 95 minutes,

(ii) a residence time that proceeds thermal cracking of the heavy oil in such a range that a formation amount of coke is from 0 to 20% by weight of the heavy oil component, and

(iii) a residence time that proceeds thermal cracking of the heavy oil to such an extent that a kinematic viscosity of the heavy oil component at 350°C is 3.0×10^{-5} m^2/s or less.

[Claim 12]

The apparatus for producing an upgraded oil according to any one of claims 7 to 11, wherein the apparatus comprises a controlling part that controls a feeding amount of the supercritical water to the reactor to such an amount that a residence time of the effluent from the second phase is one of:

(i) the residence time of the effluent from the second phase in a range of from 1 to 25 minutes, for suppressing excessive cracking of the light oil component,

(ii) a residence time that proceeds thermal cracking of the heavy oil in such a range that a formation amount of gas due to excessive cracking is from 0 to 5% by weight of the heavy oil, and

(iii) a residence time that proceeds thermal cracking of the heavy oil to such an extent that a kinematic viscosity of the light oil component at 10°C is 5.0×10^{-3} m^2/s or less.

Fig.1

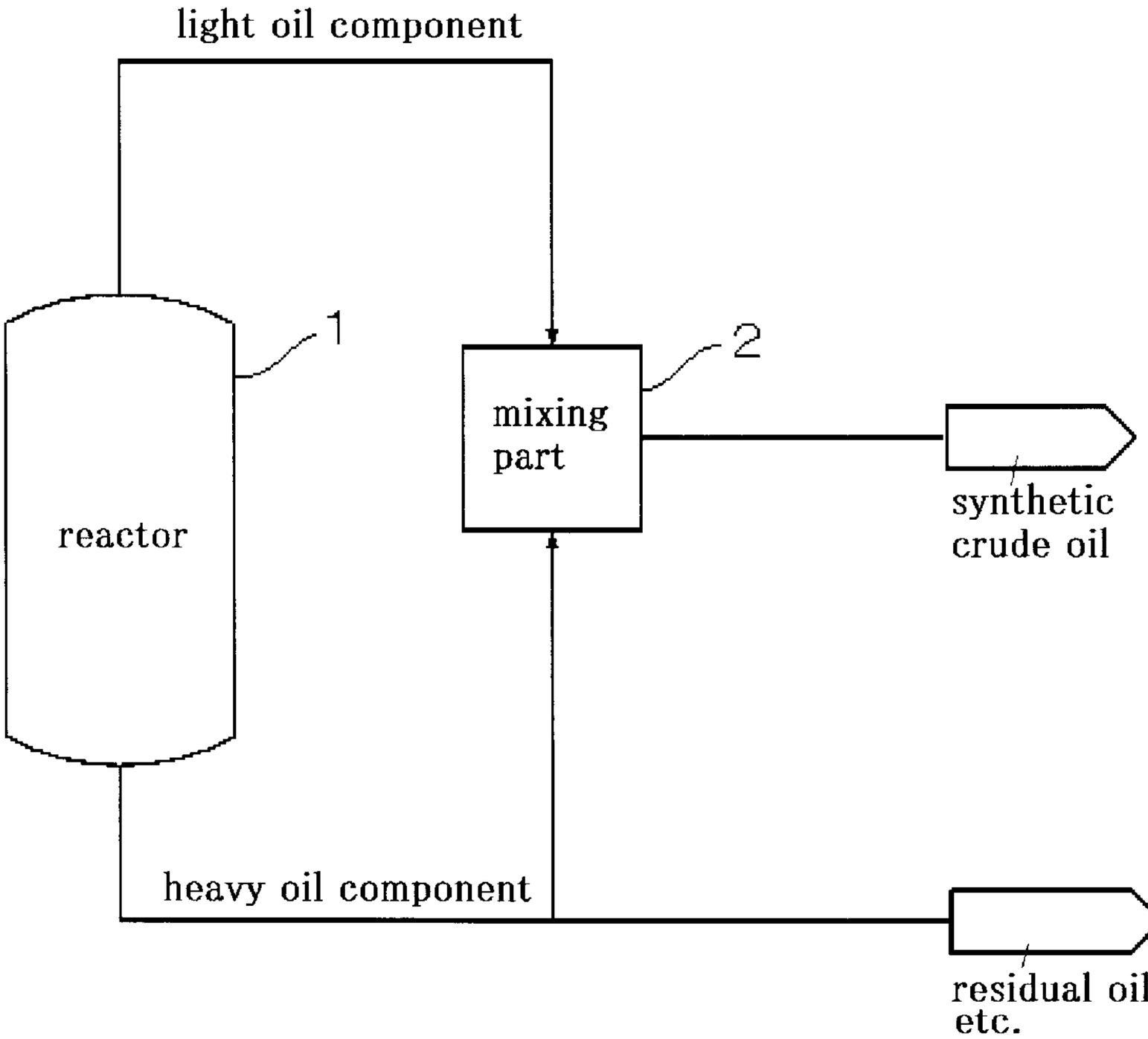

light oil component
1
2
reactor
mixing part
synthetic crude oil
heavy oil component
residual oil, etc.

Fig.2

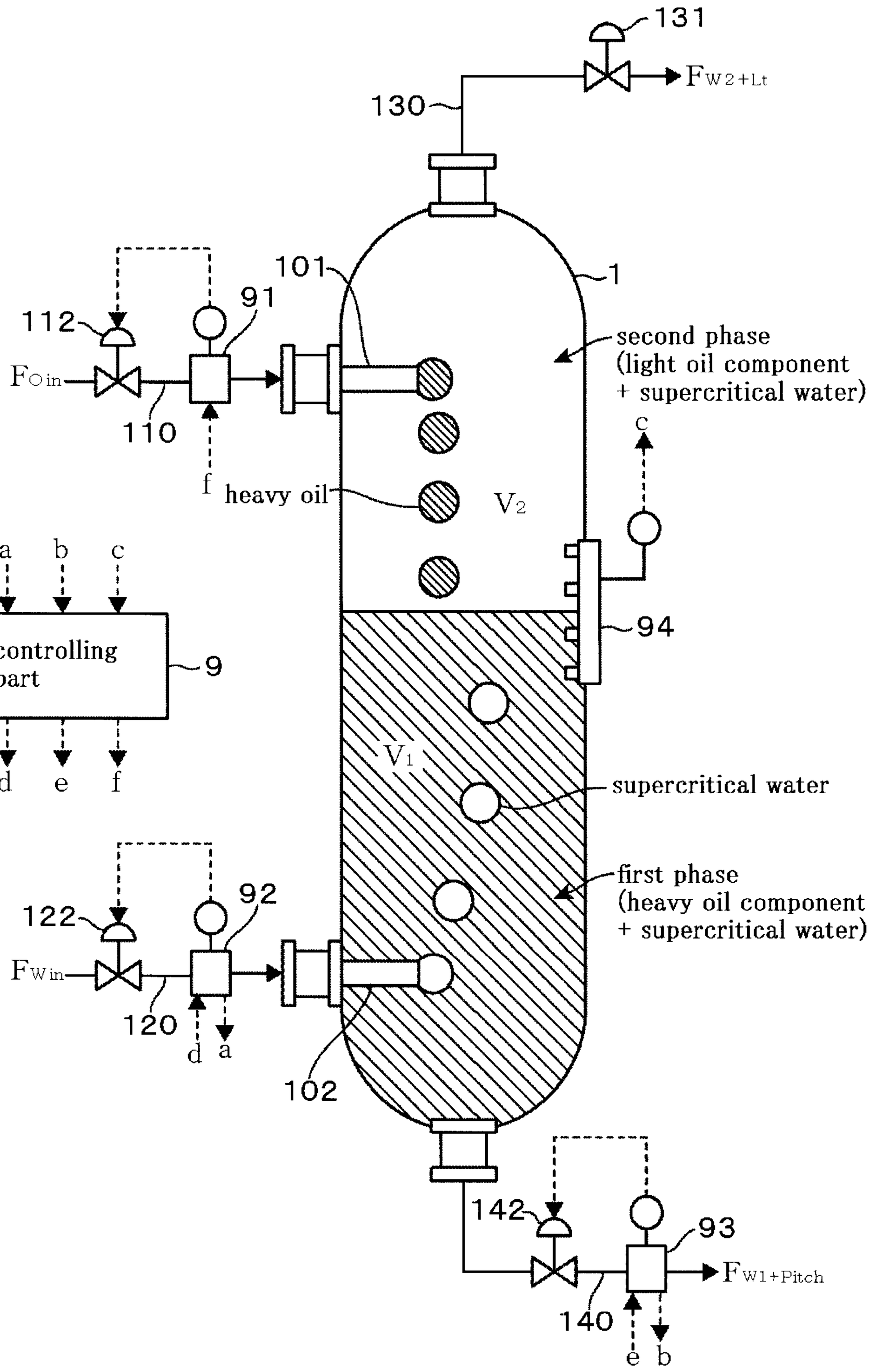

131
F_{W2+Lt}
130
101
1
91
112
$F_{O\,in}$
110
f
heavy oil
second phase
(light oil component
+ supercritical water)
c
V_2
a
b
c
94
controlling
part
9
V_1
supercritical water
d
e
f
92
122
$F_{W\,in}$
120
d
a
first phase
(heavy oil component
+ supercritical water)
102
142
93
$F_{W1+Pitch}$
140
e
b

Fig.3

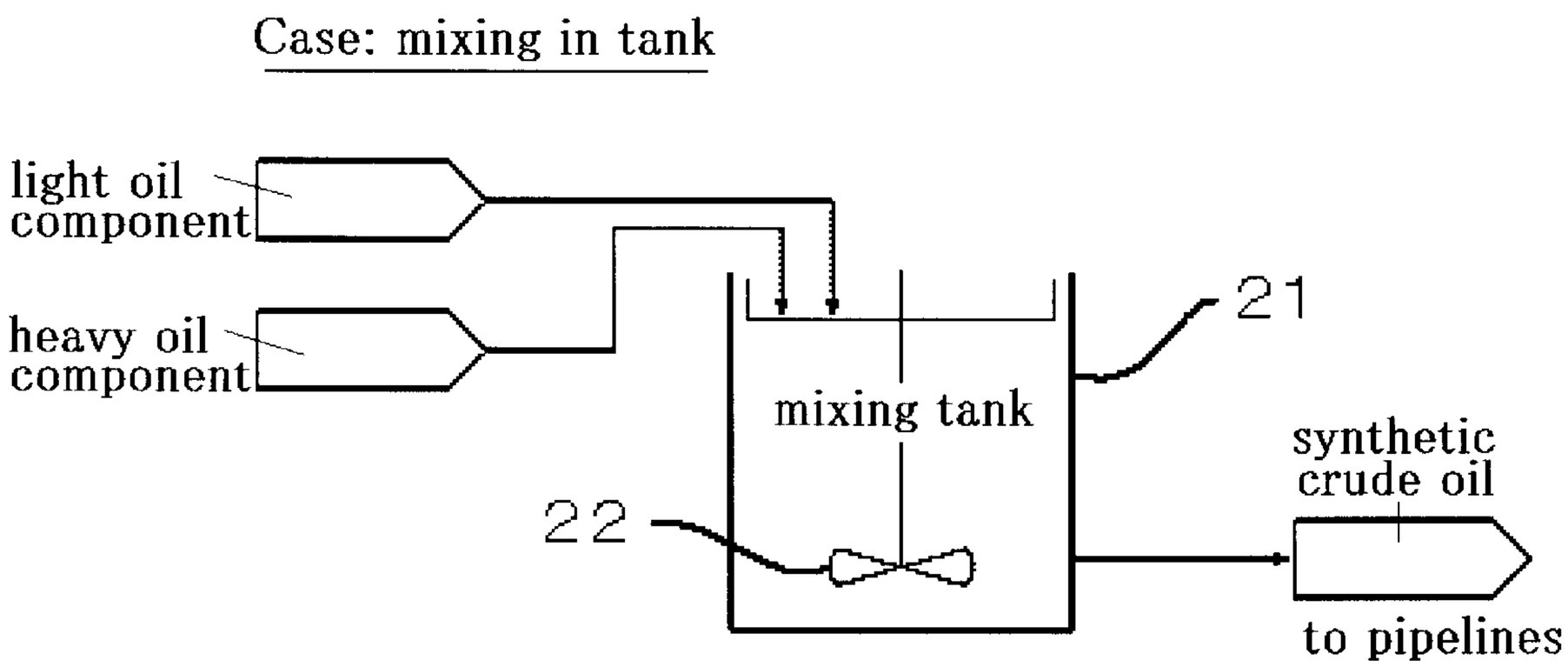

Case: mixing in tank
light oil component
heavy oil component
mixing tank
21
22
synthetic crude oil
to pipelines

Fig.4

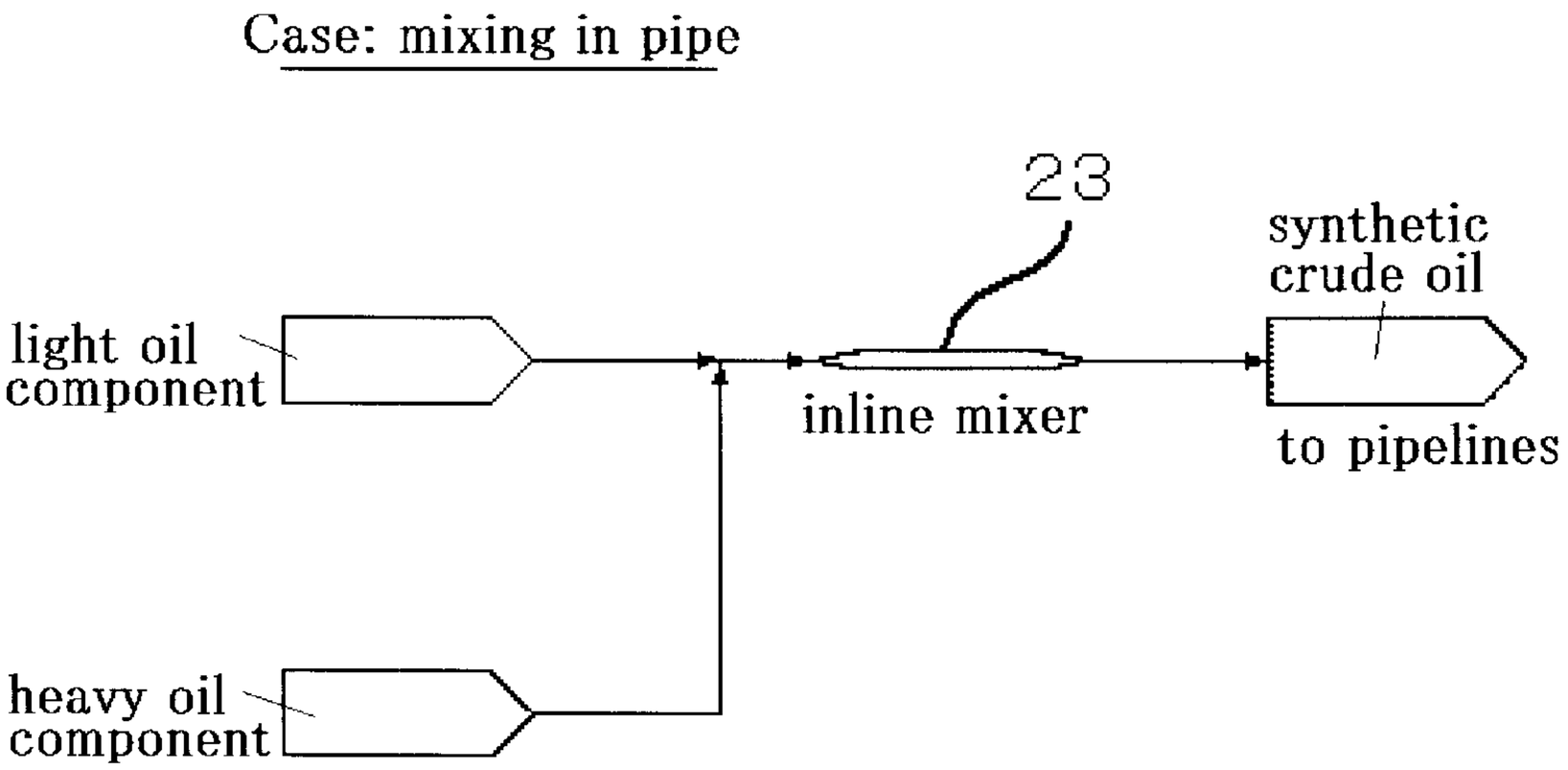

Case: mixing in pipe
23
synthetic
crude oil
light oil
component
inline mixer
to pipelines
heavy oil
component

Fig.5

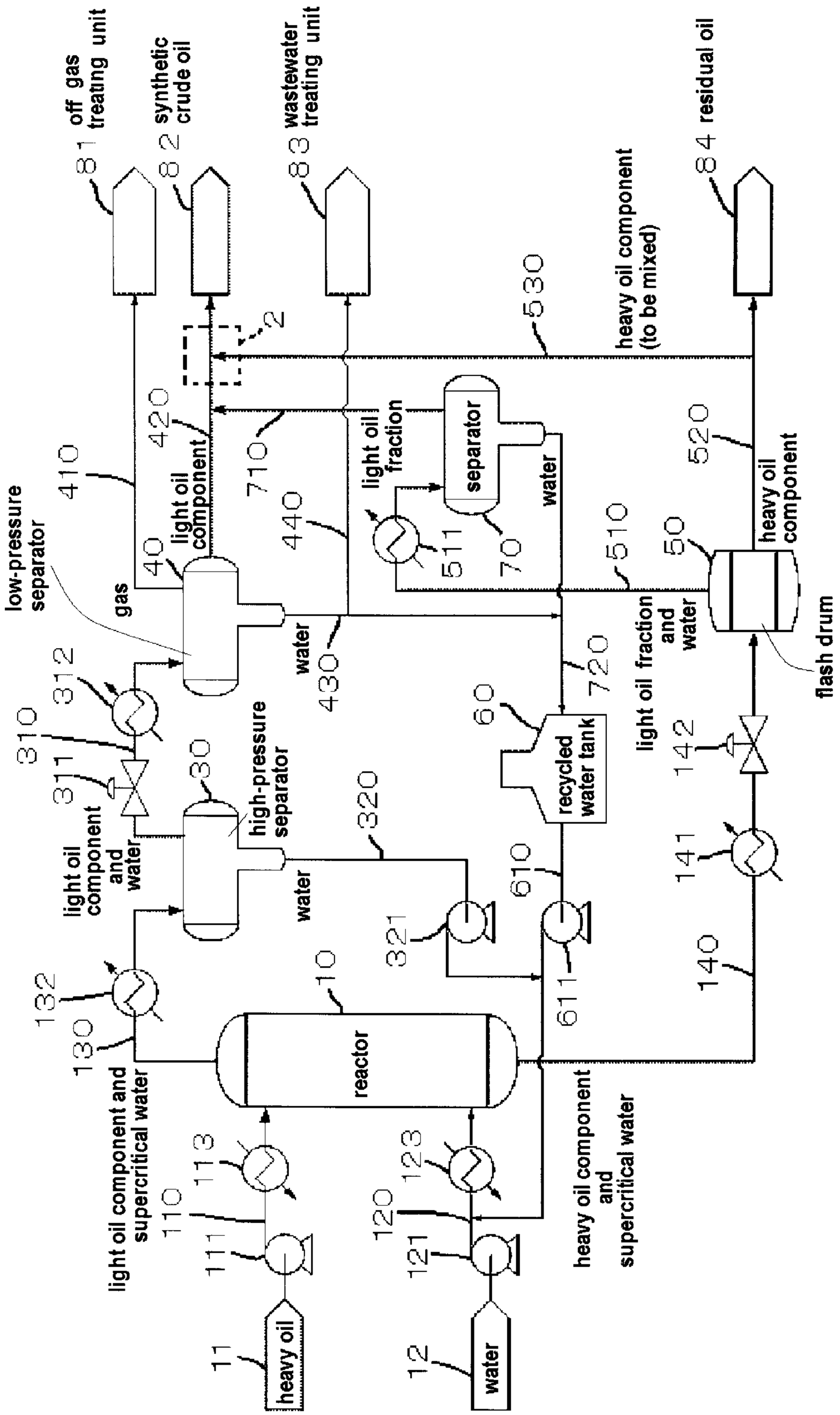
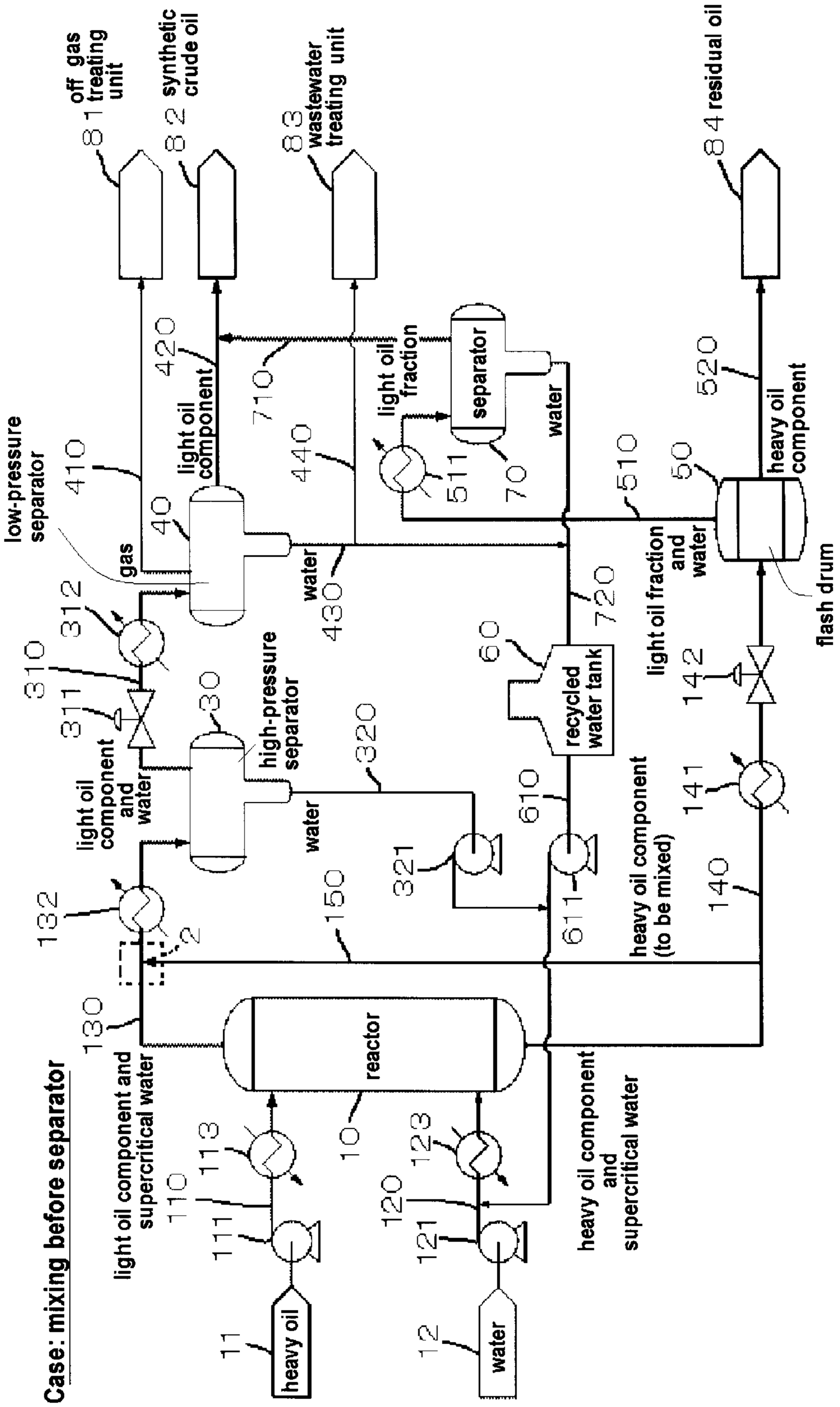

Case: mixing after separator
81 off gas treating unit
82 synthetic crude oil
83 wastewater treating unit
84 residual oil
530
heavy oil component (to be mixed)
2
low-pressure separator
410
420
light oil component
40
gas
710
440
light oil fraction
separator
511
70
water
520
heavy oil component
510
50
flash drum
light oil fraction and water
720
60
recycled water tank
310
312
311
30
high-pressure separator
320
water
430
light oil component and water
132
130
light oil component and supercritical water
10
reactor
321
610
611
heavy oil component and supercritical water
142
141
140
110
113
111
11
heavy oil
120
123
121
12
water

Fig.6


off gas treating unit
81
synthetic crude oil
82
wastewater treating unit
83
residual oil
84
low-pressure separator
40
gas
410
light oil component
420
water
430
440
light oil fraction
separator
70
511
710
water
510
50
heavy oil component
520
flash drum
light oil fraction and water
recycled water tank
60
720
610
611
321
heavy oil component (to be mixed)
141
142
140
light oil component and water
high-pressure separator
30
310
311
312
320
132
2
150
130
reactor
10
light oil component and supercritical water
110
111
113
120
121
123
heavy oil component and supercritical water
Case: mixing before separator
11
heavy oil
12
water