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(54) **An integrated process for the conversion of heavy hydrocarbons to a light distillate and/or mid-distillate**

Integriertes Verfahren zur Umwandlung von schweren Kohlenwasserstoffen zu einem leichten Destillat und/oder mittleres Destillat

Procédé intégré pour la conversion d'hydrocarbures lourds sur un distillat léger et/ou mi-léger

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US-A- 4 192 734 **US-A- 4 983 273**
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Description**Field of the invention**

[0001] The invention generally relates to the upgrading of residues of heavy hydrocarbon residues and relates in particular to an integrated process including catalytic cracking, hydrocracking and hydroconversion in order to convert a wide range of heavy hydrocarbons such as crude oil, the residues of atmospheric and vacuum distillation, asphaltene, coking heavy oil, visbreaking, natural bitumen, and sand oils to more valuable products like diesel and/or kerosene.

Background

[0002] Advances in the automotive industry and the extensive use of gasoline or diesel combustion engines, have increased the demand for processes for conversion of heavy hydrocarbon feedstocks to mid-distillate products, especially to gasoline and diesel of low sulfur content.

[0003] Due to the high cost of low-sulfur gasoline and diesel and the reduced consumption of heavy refinery products, processes for the conversion of heavy hydrocarbon feedstocks are both essential and economical, and hence, many efforts have been made to change a heavy oil feedstock to lighter products through the integration of upgrading processes.

[0004] US patent No. 3,891,538 discloses an integrated hydrocarbon conversion process, in which a crude oil feedstock is first desulfurized before entering a distillation tower. The fraction with the boiling point in the range between 344°C and 538°C enters a catalytic cracking process and the bottom flow of the catalytic cracking unit is sent to a coking unit. Application of the coking process, in this process, yields gasoline of high sulfur content. Furthermore, a fraction of the product is converted to coke, reducing the efficiency of the process.

[0005] US patent No. 3,072,560 discloses a process for the integration of coking, hydrocracking, catalytic cracking and reforming units to convert the heavy residues of atmospheric distillation to gasoline, in which, as a result of the presence of the coking unit, the yield is low and the product has a high sulfur content. Upgrade of the heavy feedstock is performed by the use of a coker unit which produces high amounts of coke, while having a low gasoline yield. The high gasoline yield is based on coker gas oil and not on the feed stock. The process can just increase the gasoline yield due to the separate arrangement of a hydrocracking unit and catalytic cracking unit.

[0006] The process disclosed in US patent No. 3,983,029 includes the integration of the hydrocracking, reforming and catalytic cracking units according to which the outlet of the hydrocracking process is sent to the catalytic cracking unit. A fraction of the same stream is returned to the hydrocracking unit and the naphtha of the hydrocracking unit is sent to the reforming unit. The outlet of this process still contains heavy residues.

[0007] The process disclosed in US patent No. 4,354,922 includes the integration of the processes of catalytic cracking of heavy hydrocarbons without hydrogen, hydroconversion and solvent separations. In this process, the outlet of the hydroconversion together with the heavy hydrocarbon feedstock is purified and then sent to the hydroconversion, distillation and the catalytic cracking unit. This process requires several steps and operating apparatus for the preparation of the catalytic cracking feedstock and the purification of heavy stream. The heavy hydroconversion stream is recycled indirectly to the catalytic cracking process, according to this integrated process. The process has, however, a high sulfur diesel yield and there is no control on production of gasoline and diesel.

[0008] US patent No. 4,426,276 discloses an integrated combination of fluid catalytic cracking with hydrocracking to produce gasoline and to optimize hydrogen consumption. In this process the species, heavier than mid-distillates, are separated from the hydrocracking products and are returned to the catalytic cracking unit. The naphtha fractions of the distillation tower, the catalytic cracking and hydrocracking are converted to gasoline through reforming and alkylation. The products of the process comprise refinery gases, gasoline, and mid-distillates. However a portion of the feed, remains as a slurry and fuel oil.

[0009] US patent No. 5,026,472 discloses the integration of hydrocracking and hydrogenation units. Heavy (high boiling) hydrocarbons are converted to mid-distillates like kerosene and jet fuel in the hydrogenation reactor. However, during the process, some of the feedstock is converted to fuel oil and other high-boiling point residues, reducing the overall yield of the process.

[0010] The process disclosed in US patent No. 6,123,830, is on the integration of catalytic cracking and hydro-processing processes. Although this process aims at maximizing the olefin yield, the octane number of the cracking products and also the quality of mid-distillates, some heavy (high boiling) products are also yielded.

[0011] GB-A-1 270 607 discloses a process for the production of motor and jet fuels by a processing sequence involving hydrocracking and hydrotreating. Hydrotreating, which occurs in a hydrotreating zone, where little or preferably no cracking occurs, is used to saturate aromatics. Both the hydrocracking and hydrotreating zone cannot tolerate heavy hydrocarbons such as crude oils. Instead the feed of the hydrocracking and hydrotreating zones is a hydrocarbon with a boiling point in the range of gas oil, cracked gas oil fraction and heavy naphtha-kerosene.

[0012] US-A-4,983,273 discloses the recycling of a portion of unconverted hydrocracked to hydrocracking zone and

hydrotreater in order to increase distillate. The task of the hydrotreater is just to saturate aromatics and remove nitrogen and sulfur present in the feed without substantial cracking the hydrocarbonaceous feedstock. As the light products are not produced in the hydrotreater, the entire effluent is introduced to the hydrocracker so that catalyst deactivation of the hydrocracking zone cannot be delayed. As a portion of the unconverted fraction of the feed is recycled to the hydrocracking zone, the outlet of the process contains the heavy residue.

[0013] GB patent No. 1,270,607 discloses a process integrating fluid catalytic cracking, hydrocracking and hydrotreating to convert gas oil fractions to motor and jet fuel.

Summary of the invention

[0014] It is an object of the present invention to provide a process which enables a highly efficient and economical conversion of heavy hydrocarbons to light distillates and/or mid-distillates.

[0015] The above and further objects are accomplished by a integrated process according to claim 1. Further advantageous embodiments are the subject-matter of the dependent claims.

[0016] According to the present invention the processes of hydroconversion, hydrocracking and catalytic cracking are integrated. According to the subject matters of the present invention all of the heavy products (where heavy means heavier than the diesel fraction) are returned to the catalytic cracking, hydrocracking and hydroconversion units to produce lighter products. Thus, according to the present invention the yield of heavy hydrocarbons can be minimized to approach or even reach zero. In addition, the subject matter of the present invention leads to an increase in the production of mid-distillate products as well. According to the present invention, the yields of gasoline and/or diesel products can be adjusted to increase or decrease as desired, simply by varying the ratio of the recycling stream of heavy hydroconversion products of the hydroconversion unit to the catalytic cracking unit to the recycling stream of heavy hydroconversion products of the hydroconversion unit to the hydrocracking unit.

[0017] According to the present invention there is provided an integrated process for the conversion of heavy hydrocarbons to a light distillate and/or mid-distillate, comprising the steps of: a) Hydrocracking of a feedstock of heavy hydrocarbons in a hydrocracking unit; b) Distillation of the products of the hydrocracking unit from step a) to produce a first residue of heavy hydrocarbons; c) Catalytic cracking of a feedstock of heavy hydrocarbons in a catalytic cracking unit; d) Distillation of the products of the catalytic cracking unit from step c) to produce a second residue of heavy hydrocarbons; e) Hydroconversion of the second residue of heavy hydrocarbons from step d) with the addition of heavy hydrocarbons in a hydroconversion unit; f) Recycling the heavy hydroconversion products of the hydroconversion unit from step e) to the hydrocracking unit in step a) or both to the hydrocracking unit in step a) and to the catalytic cracking unit in step c); and g) Feeding (recycling) at least a portion of the first residue of heavy hydrocarbons from step b) to the hydroconversion unit in step e).

[0018] The feedstock of heavy hydrocarbons to the hydrocracking process or unit is one or a mixture of fractions of light and vacuum gas oil, coking gas oil and visbreaking, the boiling point of which is in the range between 260°C and 590°C and preferably in the range between 285°C and 520°C.

[0019] The hydrocracking in the present invention can be one of the conventional processes known to the person skilled in the art.

[0020] In the hydrocracking unit or process, heavy fractions are converted to more valuable products like naphtha, kerosene, diesel and LPG (liquefied petroleum gases). By choosing the proper reactor (hydrocracking) conditions and using proper catalysts one can increase the selectivity of the process towards mid-distillates or naphtha. Cracking of the heavy fractions to lighter compounds occurs under high pressure and in the presence of hydrogen and a suitable catalyst.

[0021] In a process according to this invention, the hydrocracking of heavy oil fractions can be performed at temperatures in the range between 340°C and 400°C, at a space velocity in the range between 0.6 h⁻¹ and 1.3 h⁻¹ and at a pressure in the range between 30 bar and 200 bar. The present invention can be used in the case of any common hydrocracking catalysts.

[0022] The feedstock of the catalytic cracking process is a fraction or mixture of fractions of light or heavy vacuum gas oil, and vacuum heavy slops, atmospheric residues, coking and visbreaking gas oil or desulfurized or demetalized fractions. The boiling point of the feedstock mixture is in the range between 240°C and 620°C and higher, and preferably in the range between 265°C and 595°C.

[0023] The invention can use different common catalytic hydroconversion processes.

[0024] In the catalytic cracking unit, heavy oil fractions are cracked in contact with small catalyst particles and are converted to lighter compounds.

[0025] All hydroconversion processes in which the boiling point of the heaviest products is at most 620°C, and preferably hydroconversion processes which do not undergo coking which satisfy the above mentioned boiling point requirement are used in the process according to the present invention. In case the process undergoes coking, the heavy product is de-coked before entering the hydrocracking unit or before entering both the catalytic-cracking and hydrocracking unit.

In addition to the heavy products of the distillation tower after the catalytic cracking, one or a combination of heavy hydrocarbon streams such as crude oil, atmospheric and vacuum residues, asphaltene, heavy coking and visbreaking gas oil, natural bitumen and sand oils can be used as the hydroconversion feed.

[0026] All common hydroconversion processes can be used according to the present invention such as the disclosed processes in patents US 6,004,454, US 7,214,309, EP 1 754 770 A1 and US 7,238,273 the whole contents of which are hereby incorporated.

[0027] According to the present invention, the heavy hydrocarbon products of the hydroconversion unit from step e), which are heavier than diesel (of the single distillation unit or from the plural distillation units downstream of the hydroconversion reactor), are recycled to the hydrocracking unit or both to the catalytic cracking unit and to the hydrocracking unit. By changing the ratio of the recycling stream of heavy hydroconversion products of the hydroconversion unit from step e) to the catalytic cracking unit to the recycling stream of heavy hydroconversion products of the hydroconversion unit from step e) to the hydrocracking unit, one can adjust the amount of the gasoline or diesel production. This ratio can be in the range between 0 and 0.99, more preferably in the range between 0.1 and 0.3 and most preferably in the range between 0.13 and 0.16. An increase of the recycling stream to the hydrocracking unit(s) leads to an increase in the diesel yield while an increase of the recycling stream to the catalytic cracking unit(s) boosts the gasoline production yield.

[0028] According to another embodiment, a portion of the first residue of heavy hydrocarbons of the hydrocracking unit (from step b)) are fed to the hydroconversion. According to the present invention, all of the heavy products (the entire first residue of heavy hydrocarbons) of the hydrocracking unit enter the hydrocracking unit and/or hydroconversion unit.

[0029] The term hydroconversion as used in this application generally refers to a form of hydrocracking in which hydrogenation and cracking occur simultaneously.

[0030] More specifically, a hydroconversion process in the sense of this application may be a catalytic hydrocracking process for deep upgrading of heavy residues/ heavy crude oil with the purpose of maximizing distillates. The main objective of this process is the breakup of high molecular hydrocarbons in order to obtain light and medium molecular hydrocarbon. This process is one of the most effective methods of getting light products through deep upgrading of heavy residues.

[0031] In an exemplary hydroconversion process two types of reactions, namely, cracking and mild hydrogenation may occur simultaneously.

[0032] In the hydroconversion process the hydrogen, feed and the catalytic complex are heated separately. Then feed and the catalytic complex are mixed and heated again. Finally, the mixture of feed, catalytic complex and hydrogen are heated and entered into a reactor where heavy residue feed is cracked and hydrogenated. Outlet gas products from the top of the reactor are condensed and separated. In the first stage of separation, unreacted hydrogen and light hydrocarbon can be separated, treated e.g. in an amine contactor and recycled to the system by a compressor. In the second stage, off gas can be separated, treated e.g. in amine contactor and conducted to the flare system. After separation, liquid products are fractionated by distillation.

Brief Description of Drawings

[0033] In the following, the invention will be described in an exemplary manner and with reference to the accompanying drawings, from which further features, advantages and problems to be solved may be derived by a person skilled in the art, and wherein:

Figure 1 illustrates the overall diagram of the process according to the present invention.

Detailed description of an embodiment according to the invention

[0034] As shown in Fig. 1, according to the present invention, the hydrocracking (HCR) feedstock 1 comprising one or a mixture of light or heavy vacuum gas oil, coking or visbreaking gas oil together with the recycling stream 3 of the hydroconversion unit 25 are sent to the HCR unit 4. The outlet 5 of the HCR (hydrocracking) reactor 4 is sent to the distillation tower 6 and is distilled to light gaseous products and LPG (liquefied petroleum gases) as indicated by reference numeral 7, light naphtha with a boiling point of at most 90°C as indicated by reference numeral 8, heavy naphtha with a boiling point range between 90°C and 160°C as indicated by reference numeral 9, kerosene with a boiling point in the range between 160 and 290°C as indicated by reference numeral 10, hydrocracking diesel with a boiling point in the range between 290°C and 390°C as indicated by reference numeral 11, and the HCR offset (residue) as indicated by reference numeral 12 with a boiling point above 390°C.

[0035] The light and heavy naphtha produced (streams 8 and 9) can be sent to the isomerization and catalytic reforming units respectively (not shown), for quality improvement. Stream 12, i.e. the residue of the hydrocracking unit 4 with a

boiling point range above 390°C, can be divided into two substreams 2 and 13 or optionally can be divided into three sub-streams 2, 13 and 14, in each case with adjustable ratios of the substreams. In Fig. 1, the substreams 2 and 14 are each indicated by a dashed line.

[0036] Preferably, the stream 12 is only divided into two sub-streams 2 and 13. In each of the afore-mentioned configurations, stream 2 is used as the hydrocracking feedstock, i.e. the feedstock to the hydrocracking unit 4, and stream 13 is fed to the hydroconversion unit 25. Furthermore, stream 14 (in case it is desired under the specific operating conditions) can be fed to the catalytic cracking unit 17. The branching ratio of the stream 12 into substreams 2 and 14 can be adjusted freely and can be set to zero even. In such a case, the stream 12 would be sent as a stream 13, i.e. a stream of the residue of the hydrocracking unit 4 with a boiling point range above 390°C, only to the hydroconversion unit 25, whereas streams 2 and 14 would not exist at all, as indicated by the dashed lines in Fig. 1.

[0037] The hydrocracking unit 4 can be operated with or without a recycling stream as feedstock. According to the present invention, all heavy products of the hydrocracking unit 4, i.e. the residue 12 of the hydrocracking unit 4, can be sent either to the hydroconversion unit 25 or to the hydroconversion unit 25 and to one or more catalytic-cracking unit 17.

[0038] The catalytic cracking (FCC) feedstock 15, i.e. the feedstock 15 to the catalytic cracking unit 17, comprises one or a mixture of the following products: atmospheric and vacuum residues, heavy or light atmospheric and vacuum gas oil, heavy vacuum slops and coking and visbreaking gas oil. Furthermore, the hydrocracking residue 14 and/or the recycling stream 16 of the hydroconversion unit 25 can be fed to the catalytic cracking unit 17. According to the present invention, the ratio of the recycling stream 16 from the hydroconversion unit 25, which is fed to the catalytic cracking unit 17, to the recycling stream 3 from the hydroconversion unit 25, which is fed to the hydrocracking unit 4, can be adjusted freely to be in the range between 0 and 0.99, more preferably in the range between 0.1 and 0.3 and most preferably in the range between 0.13 and 0.16.

[0039] The products 18 of the catalytic cracking unit 17 are sent to the distillation tower 19. The output of this distillation tower 19 consists of light products, liquefied petroleum gases (LPG) as indicated by reference numeral 20, catalytic cracking gasoline with boiling points of less than 180°C as indicated by reference numeral 21, mid-distillates or light cycle oil (LCO) with a boiling point in the range between 180°C and 370°C as indicated by reference numeral 22 and a heavy product as indicated by reference numeral 23 which consists mainly of clarified cycle oil (CSO) with a boiling point above 370°C. Kerosene and diesel are produced from LCO 22 after its desulphurization and distillation.

[0040] Stream 23, i.e. the heavy products with a boiling point above 370°C, can be sent to the hydroconversion unit 25 together with a stream of one or a mixture of crude oil, heavy residues of refineries like the heavy residue of the coking unit or visbreaking, residues of atmospheric or vacuum towers, residues of the asphaltene or other thermo-cracking units, natural bitumen and sand oils (which stream is indicated by reference numeral 24 in Fig. 1), together with un-cracked substances 13 of the hydrocracking unit 4. The outlet of the distillation units of the hydroconversion unit 25 includes light products and LPG as indicated by reference numeral 26, hydroconversion gasoline with a boiling point of less than 180°C as indicated by reference numeral 27, hydroconversion diesel with a boiling range between 180°C and 370°C as indicated by reference numeral 28 and heavy hydroconversion product with a boiling point above 370°C as indicated by reference numeral 31. The heavy hydroconversion product 31 of the hydroconversion unit 25 is recycled as a feedstock 16 to the catalytic cracking unit 17 and/or as a feedstock 3 to the hydrocracking unit 4.

[0041] Streams 29 and 30 supply the hydrogen required by the hydrocracking unit 4 and hydroconversion unit 25, respectively. According to the process shown in Fig. 1, the stream 3, which is recycled to the hydrocracking unit 4, leads to increases in the diesel production yield and the yield of products heavier than diesel approaches zero. By changing the ratio of the recycling stream 3, which is fed to the hydrocracking unit 4, to the recycling stream 16, which is fed to the catalytic cracking unit 17, the yields of the products can be changed in favor of diesel or gasoline as desired.

[0042] The following examples illustrate representative teachings of features of the present invention. It is noted, however, that such examples should not be construed as being exclusive embodiments. All examples refer to a process plant as shown in Fig. 1.

Example 1

[0043] Vacuum gas oil (VGO) entered the hydrocracking unit containing a nickel-molybdenum catalyst with a rate of 240,900 bbl/day as the feedstock and it was cracked in the presence of H₂ gas at the temperature and pressure of about 380°C and 194 bar, respectively. The hydrocracking unit had two four bed reactors, the total catalyst weight on which was 67 Tons. About 131,500 bbl/day of the cracking offset (residue) was remixed with the new feedstock (fresh VGO) and returned to the hydrocracking reactor.

[0044] The specifications of the hydrocracking product are shown in table 1.

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Table 1- The products of the hydrocracking in example 1

Product Rate		
L.Naphtha	bbl/day	1,733
H.Naphtha	bbl/day	3,079
Kerosene	bbl/day	10,110
Diesel	bbl/day	11,370
OffTest	bbl/day	674.3

[0045] In Table 1, L.Naphta stands for light naphta, whereas H.Naphta stands for heavy. Light vacuum gas oil (LVGO), heavy vacuum slops (HVS), the atmospheric residue and heavy atmospheric gas oil (HGO), each having rates of 10,430 bbl/day, 9,568 bbl/day, 60,860 bbl/day and 5,344 bbl/day respectively, were mixed to yield the catalytic cracking feedstock with a rate of 86,200 bbl/day. The feedstock had a specific density of 0.94, a sulfur content of 1 wt%, a (Ni + V) content of about 14.723 ppm(wt) and a boiling point in the range between 264.5°C and 592.6°C. The catalytic cracking reactions occurred in the presence of a USY catalyst (zeolite catalyst of ultrastable Y-type) in an amount of 300 tons, at a temperature of about 525 °C and at a pressure of about 11bar. The feedstock was converted to lighter products according to table 2.

Table 2- The products of the catalytic cracking of example 1

Product Rates		
FRCG (Gasoline)	bbl/day	42,810
LCO	bbl/day	27,480
CSO	bbl/day	8,951

[0046] All CSO (clarified cycle oil) and offset material (heavy products of the catalytic cracking unit and heavy products of the hydrocracking unit) were sent to the hydroconversion unit in accordance with the teaching of European patent application EP 1 754 770 A1 of the applicant, the whole content of which is hereby incorporated by reference. The catalyst used in this unit was an aqueous molybdenum -ammonium catalyst. The products of this step are summarized in table 3.

Table 3 - The hydroconversion products of example 1

Product Rates		
Gasoline	bbl/day	2,326
Diesel	bbl/day	4,535
Heavier than diesel	bbl/day	2,914

[0047] The total gasoline produced according to the afore-mentioned process, which is a mixture of light and heavy naphtha, and fluid catalytic cracking and hydroconversion gasoline, is 49,948 bbl/day and the total (hydrocracking and hydroconversion) diesel equals 15,905 bbl/day. In this case, in the hydroconversion unit, approximately 2,914 bbl/day uncracked hydrocarbon (heavier than diesel) is produced.

Example 2

[0048] Under identical operating conditions as example 1 for the hydrocracking unit, catalytic cracking unit and hydroconversion unit, the heavy outlet stream of the hydroconversion unit was returned to the catalytic cracking unit, in order to stabilize the flow rate of the feedstock of the catalytic cracking unit, a fraction of the atmospheric residue of the catalytic cracking unit, namely about 5,051 bbl/day, was sent to the hydroconversion unit.

[0049] The products of the hydrocracking, catalytic cracking and hydroconversion units, under these conditions are summarized in tables 4 to 6 respectively.

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Table 4- The hydrocracking products of example 2

Product Rate		
L.Naphtha	bbl/day	1,733
H.Naphtha	bbl/day	3,079
Kerosene	bbl/day	10,110
Diesel	bbl/day	11,370
OffTest	bbl/day	674.3

Table 5- The FCC products of example 2

Product Yields		
FRCG (Gasoline)	bbl/day	42,310
LCO	bbl/day	28,550
CSO	bbl/day	8,959

Table 6- The hydroconversion products of example 2

Product Rates		
Gasoline	bbl/day	3,547
Diesel	bbl/day	6,523
Heavier than diesel	bbl/day	5,040

[0050] The total gasoline and diesel in this example equals 50,669 bbl/day and 17,893 bbl/day which have totally increased by 4.15 % as compared to example 1, given that the feedstock and operating conditions are identical.

[0051] The heavy product (heavier than the mid- distillates) equals zero.

Example 3

[0052] In accordance with Fig. 1 and the teaching of the present invention, the process was performed under the same hydrocracking, catalytic cracking and hydroconversion operating conditions as for example 1 and the heavy outlet of the hydroconversion unit was recycled as a recycling stream to the hydrocracking unit. In order to stabilize the flow rate of the feedstock of hydrocracking unit, an amount of about 5,709 bbl/day of the output of the hydrocracking unit was sent to the hydroconversion unit. The products of the hydrocracking unit, catalytic cracking unit and hydroconversion unit are summarized in tables 7 to 9 below.

Table 7- The hydrocracking products in example 3

Product Rate		
L.Naphtha	bbl/day	835.6
H.Naphtha	bbl/day	1,694
Kerosene	bbl/day	8,943
Diesel	bbl/day	12,710
OffTest	bbl/day	2,981

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Table 8- The catalytic cracking products in example 3

Product Yields		
FRCG (Gasoline)	bbl/day	42,810
LCO	bbl/day	27,480
CSO	bbl/day	8,951

Table 9- The products of the hydroconversion unit in example 3

Product Rates		
Gasoline	bbl/day	4,087
Diesel	bbl/day	7,568
Heavier than diesel	bbl/day	6,257

[0053] The total gasoline and diesel produced according to this example and the teaching of the present invention are 49,426.6 bbl/day and 20,278 bbl/day, respectively, which represents an increase in total of about 5.84 % as compared to example 1. It is to be noted that this increase could be obtained under the same feedstock and operating conditions. The yield of the heavy product (heavier than the mid-distillates) equals zero.

Example 4

[0054] In accordance with Fig. 1 and the teaching of the present invention, the process was performed under the same hydrocracking, catalytic cracking and hydroconversion operating conditions as set forth for example 1 above, but with the following deviations:

- 85% of the heavy outlet of the hydroconversion unit was recycled and fed as a recycling stream to the hydrocracking unit; and
- 15% of the heavy outlet of the hydroconversion unit was recycled and fed as a fluid recycling stream to the catalytic cracking unit.

[0055] In order to stabilize the flow rate of the feedstocks, an amount of about 5,781 bbl/day of the fresh feed of the hydrocracking unit (VGO) and 1,826 bbl/day of the fresh feed of fluid catalytic unit (atmospheric residue) were sent to the hydroconversion unit. The products of the hydrocracking unit, catalytic cracking unit and hydroconversion unit are summarized in tables 10 to 12 below.

Table 10- The hydrocracking products in example 4

Product Rates		
L.Naphtha	bbl/day	881.2
H.Naphtha	bbl/day	1,831
Kerosene	bbl/day	8,976
Diesel	bbl/day	12,540
OffTest	bbl/day	2,536

Table 11- The catalytic cracking products in example 4

Product Rates		
FRCG (Gasoline)	bbl/day	41,990
LCO	bbl/day	27,430
CSO	bbl/day	2,013

Table 12- The products of the hydroconversion unit in example 4

Product Rates		
Gasoline	bbl/day	4,436
Diesel	bbl/day	8,142
Heavier than Diesel	bbl/day	6,943

[0056] The total gasoline and diesel produced according to this example and in accordance with the teaching of the present invention are 49,138.2 bbl/day and 20,682 bbl/day, respectively, which is an increase of the total output of about 6.02 % as compared to example 1. It is to be noted that this increase was achieved under the same feedstock and operating conditions. The yield of the heavy product (heavier than the mid-distillates) equals zero.

[0057] To summarize, the integrated process according to the present invention enables the complete conversion of heavy hydrocarbons to light products of at most diesel range. The yield of the integrated process according to the present invention is 100% for light gases, gasoline and mid-distillates. The integration of the catalytic cracking, hydrocracking and hydroconversion together with the application of recycled flows as set forth above leads to an increase in the yield of mid-distillate products as compared to the prior art. By changing the ratio of the recycling streams, the product yield of the integrated process can be switched to a higher gasoline or diesel output.

[0058] Another significant advantage of the integrated process according to the present invention is that gasoline and diesel with a low sulfur content can be produced in an efficient and economical manner.

[0059] Although the accompanying Fig. 1 shows only a single hydrocracking unit, hydroconversion unit and catalytic cracking unit, it will become apparent for a person skilled in the art that these individual units may also be replaced by a plurality of such units in a suitable interconnection.

Claims

1. An integrated process for the conversion of heavy hydrocarbons to a light distillate and/or mid-distillate, comprising the steps of:

a) Hydrocracking of a feedstock (1) of heavy hydrocarbons with the boiling point in the range between 260°C and 590°C in a hydrocracking unit (4);

b) Distillation of the products of the hydrocracking unit (4) from step a) to produce a first residue (12) of heavy hydrocarbons;

c) Catalytic cracking of a feedstock (15) of heavy hydrocarbons with the boiling point in the range between 240°C and 620°C in a catalytic cracking unit (17);

d) Distillation of the products of the catalytic cracking unit (17) from step c) to produce a second residue (23) of heavy hydrocarbons;

e) Hydroconversion of the second residue (23) of heavy hydrocarbons from step d) with boiling point above 370°C with the addition of one or combination of heavy hydrocarbons such as crude oil, atmospheric vacuum residues, asphaltene, heavy coking and visbreaking gas oil, natural bitumen and sand oils in a hydroconversion unit (25), wherein the boiling point of the heaviest products is at most 620°C, wherein the hydrogen, feed, and the catalytic complex are heated separately, then the feed and the catalytic complex are mixed and heated again and then the mixture of feed, catalytic complex and hydrogen are heated and entered into a reactor, wherein heavy residue feed it cracked and hydrogenated, and wherein hydrogenation and cracking occur simultaneously;

f) Recycling the heavy hydroconversion products (31; 3; 16) of the hydroconversion unit (25) from step e) with boiling point above 370°C to the hydrocracking unit (4) in step a) or both to the hydrocracking unit (4) and to the catalytic cracking unit (17) in step c); and

g) Feeding at least a portion (13) of the first residue (12) of heavy hydrocarbons from step b) to the hydroconversion unit (25) in step e).

2. The process of claim 1, wherein the heavy hydroconversion products (31; 3; 16) of the hydroconversion unit (25) from step e) are heavier than diesel and have a boiling point which is equal to or below 620°C.

3. The process of claim 1 or 2, wherein in the case of coke formation in step e), the heavy hydroconversion products

(31; 3; 16) of the hydroconversion unit (25) which are heavier than diesel are decoked before being recycled to the hydrocracking unit (4) in step a) or both to the hydrocracking unit (4) in step a) and to the catalytic cracking unit (17).

4. The process of any of the preceding claims, wherein a portion (14) of the first residue (12) of heavy hydrocarbons of the hydrocracking unit (4) from step b) is sent to the catalytic cracking unit (17).
5. The process of any of the preceding claims, wherein a portion (2) of the first residue (12) of heavy hydrocarbons of the hydrocracking unit (4) from step b) is recycled to the hydrocracking unit (4).
6. The process of any of the preceding claims, wherein the ratio of the recycling stream (16) of heavy hydroconversion products of the hydroconversion unit (25) from step e) to the catalytic cracking unit (17) to the recycling stream (3) of heavy hydroconversion products of the hydroconversion unit (25) from step e) to the hydrocracking unit (4) is in the range between 0 and 0.99.
7. The process of claim 6, wherein the ratio of the recycling stream of heavy hydroconversion products of the hydroconversion unit (25) from step e) to the catalytic cracking unit (17) to the recycling stream of heavy hydroconversion products of the hydroconversion unit (25) from step e) to the hydrocracking unit (4) is preferably in the range between 0.1 and 0.3 and more preferably in the range between 0.13 and 0.16.
8. The process of any of the preceding claims, wherein the first residue (12) of heavy hydrocarbons from step b) has a boiling point above 390°C.
9. The process of any of the preceding claims, wherein the second residue (23) of heavy hydrocarbons from step d) consists mainly of clarified cycle oil (CSO) with a boiling point above 370°C.
10. The process of any of the preceding claims, wherein products (18) of the catalytic cracking unit (17) are distilled in a distillation tower (19) and wherein kerosene and diesel are produced from mid-distillates or light cycle oil (LCO) of the distillation tower (19) with a boiling point in the range between 180°C and 370°C.
11. The process of any of the preceding claims, wherein products (5) of the hydrocracking unit (4) are distilled in a distillation tower (6) so as to produce kerosene (10) with a boiling point in the range between 160 and 290°C and hydrocracking diesel with a boiling point in the range between 290°C and 390°C.
12. The process of any of the preceding claims, wherein the ratio of the recycling stream of heavy hydroconversion products of the hydroconversion unit (25) from step e) to the catalytic cracking unit (17) to the recycling stream of heavy hydroconversion products of the hydroconversion unit (25) from step e) to the hydrocracking unit (4) is in the range between 0.13 and 0.16.

Patentansprüche

1. Integriertes Verfahren zur Umwandlung von schweren Kohlenwasserstoffen zu einem leichten Destillat und/oder mittleren Destillat, umfassend die Schritte von:
 - a) Hydrocracken einer Beschickung (1) von schweren Kohlenwasserstoffen, wobei der Siedepunkt davon im Bereich zwischen 260°C und 590°C liegt, in einer Hydrocrackeinheit (4);
 - b) Destillation der Produkte von der Hydrocrackeinheit (4) von Schritt a), wobei ein erster Rückstand (12) von schweren Kohlenwasserstoffen erzeugt wird;
 - c) katalytischem Cracken einer Beschickung (15) von schweren Kohlenwasserstoffen, wobei der Siedepunkt davon im Bereich zwischen 240°C und 620°C liegt, in einer katalytischen Crackeinheit (17);
 - d) Destillation der Produkte von der katalytischen Crackeinheit (17) von Schritt c), wobei ein zweiter Rückstand (23) von schweren Kohlenwasserstoffen erzeugt wird;
 - e) Hydroumwandlung des zweiten Rückstandes (23) von schweren Kohlenwasserstoffen von Schritt d) mit einem Siedepunkt von über 370°C mit der Zugabe von einem oder einer Kombination von schweren Kohlenwasserstoffen wie Rohöl, Atmosphärendruck-Vakuum-Rückstände, Asphalten, schwerem Verkokungs- und Viskositätsbrechungsgasöl, natürlichem Bitumen und Sandöle in einer Hydroumwandlungseinheit (25), wobei der Siedepunkt der schwersten Produkte höchstens 620°C beträgt, wobei der Wasserstoff, die Zufuhr und der katalytische Komplex separat erwärmt werden, dann die Zufuhr und der katalytische Komplex gemischt und

wieder erwärmt werden und dann das Gemisch von Zufuhr, katalytischem Komplex und Wasserstoff erwärmt und in einen Reaktor eingetragen wird, wobei schwerer Rückstand-Zufuhr gecrackt und hydriert wird, und wobei Hydrierung und Cracken gleichzeitig stattfinden;

f) Rückführen der schweren Hydroumwandlungsprodukte (31; 3; 16) von der Hydroumwandlungseinheit (25) von Schritt e) mit einem Siedepunkt von über 370°C in die Hydrocrackeinheit (4) in Schritt a) oder in sowohl die Hydrocrackeinheit (4) als auch die katalytische Crackeinheit (17) in Schritt c); und

g) Zuführen von mindestens einem Anteil (13) des ersten Rückstandes (12) von schweren Kohlenwasserstoffen von Schritt b) in die Hydroumwandlungseinheit (25) in Schritt e).

2. Verfahren nach Anspruch 1, wobei die schweren Hydroumwandlungsprodukte (31; 3; 16) der Hydroumwandlungseinheit (25) von Schritt e) schwerer als Diesel sind und einen Siedepunkt, der gleich oder niedriger als 620°C ist, aufweisen.

3. Verfahren nach Anspruch 1 oder 2, wobei im Falle von Koksbildung in Schritt e) die schweren Hydroumwandlungsprodukte (31; 3; 16) der Hydroumwandlungseinheit (25), welche schwerer als Diesel sind, dekarbonisiert werden, bevor sie in die Hydrocrackeinheit (4) in Schritt a) oder in sowohl die Hydrocrackeinheit (4) in Schritt a) als auch die katalytische Crackeinheit (17) rückgeführt werden.

4. Verfahren nach einem der vorhergehenden Ansprüche, wobei ein Anteil (14) des ersten Rückstandes (12) von schweren Kohlenwasserstoffen der Hydrocrackeinheit (4) von Schritt b) zur katalytischen Crackeinheit (17) befördert wird.

5. Verfahren nach einem der vorhergehenden Ansprüche, wobei ein Anteil (2) des ersten Rückstandes (12) von schweren Kohlenwasserstoffen der Hydrocrackeinheit (4) von Schritt b) in die Hydrocrackeinheit (4) rückgeführt wird.

6. Verfahren nach einem der vorhergehenden Ansprüche, wobei das Verhältnis des Rückführstroms (16) von schweren Hydroumwandlungsprodukten der Hydroumwandlungseinheit (25) von Schritt e) in die katalytische Crackeinheit (17) zum Rückführstrom (3) von schweren Hydroumwandlungsprodukten der Hydroumwandlungseinheit (25) von Schritt e) in die Hydrocrackeinheit (4) im Bereich zwischen 0 und 0,99 liegt.

7. Verfahren nach Anspruch 6, wobei das Verhältnis des Rückführstroms von schweren Hydroumwandlungsprodukten der Hydroumwandlungseinheit (25) von Schritt e) in die katalytische Crackeinheit (17) zum Rückführstrom von schweren Hydroumwandlungsprodukten der Hydroumwandlungseinheit (25) von Schritt e) in die Hydrocrackeinheit (4) bevorzugt im Bereich zwischen 0,1 und 0,3 und stärker bevorzugt im Bereich zwischen 0,13 und 0,16 liegt.

8. Verfahren nach einem der vorhergehenden Ansprüche, wobei der erste Rückstand (12) von schweren Kohlenwasserstoffen von Schritt b) einen Siedepunkt von über 390°C aufweist.

9. Verfahren nach einem der vorhergehenden Ansprüche, wobei der zweite Rückstand (23) von schweren Kohlenwasserstoffen von Schritt d) hauptsächlich aus geklärtem Kreislauföl (CSO) mit einem Siedepunkt von über 370°C besteht.

10. Verfahren nach einem der vorhergehenden Ansprüche, wobei Produkte (18) von der katalytischen Crackeinheit (17) in einem Destillationsturm (19) destilliert werden und wobei Kerosin und Diesel aus mittleren Destillaten oder leichtem Kreislauföl (LCO) von dem Destillationsturm (19) mit einem Siedepunkt im Bereich zwischen 180°C und 370°C hergestellt werden.

11. Verfahren nach einem der vorhergehenden Ansprüche, wobei Produkte (5) von der Hydrocrackeinheit (4) in einem Destillationsturm (6) destilliert werden, so dass Kerosin (10) mit einem Siedepunkt im Bereich zwischen 160 und 290°C und Hydrocrackdiesel mit einem Siedepunkt im Bereich zwischen 290°C und 390°C hergestellt werden.

12. Verfahren nach einem der vorhergehenden Ansprüche, wobei das Verhältnis des Rückführstroms von schweren Hydroumwandlungsprodukten der Hydroumwandlungseinheit (25) von Schritt e) in die katalytische Crackeinheit (17) zum Rückführstrom von schweren Hydroumwandlungsprodukten der Hydroumwandlungseinheit (25) von Schritt e) in die Hydrocrackeinheit (4) im Bereich zwischen 0,13 und 0,16 liegt.

Revendications

1. Processus intégré pour la transformation d'hydrocarbures lourds en un distillat léger et/ou en un distillat moyen, comprenant les étapes de :

a) hydrocraquage d'un produit de départ (1) d'hydrocarbures lourds avec le point d'ébullition dans la plage comprise entre 260 °C et 590 °C dans une unité d'hydrocraquage (4) ;
 b) distillation des produits de l'unité d'hydrocraquage (4) provenant de l'étape a) pour produire un premier résidu (12) d'hydrocarbures lourds ;
 c) craquage catalytique d'un produit de départ (15) d'hydrocarbures lourds avec le point d'ébullition dans la plage comprise entre 240 °C et 620 °C dans une unité de craquage catalytique (17) ;
 d) distillation des produits de l'unité de craquage catalytique (17) provenant de l'étape c) pour produire un second résidu (23) d'hydrocarbures lourds ;
 e) hydroconversion du second résidu (23) d'hydrocarbures lourds provenant de l'étape d) avec un point d'ébullition au-dessus de 370 °C avec l'ajout d'un seul ou d'une combinaison d'hydrocarbures lourds comme du pétrole brut, des résidus sous vide atmosphérique, de l'asphaltène, du gas-oil à viscoréduction et cokéfaction lourde, du bitume naturel et des sables bitumineux dans une unité d'hydroconversion (25), dans laquelle le point d'ébullition des produits les plus lourds est au plus de 620 °C, dans laquelle l'hydrogène, l'alimentation, et le complexe catalytique sont chauffés séparément, ensuite l'alimentation et le complexe catalytique sont mélangés et chauffés de nouveau et ensuite le mélange d'alimentation, de complexe catalytique et d'hydrogène est chauffé et entré dans un réacteur, dans lequel l'alimentation en résidus lourds est craquée et hydrogénée, et dans lequel l'hydrogénation et le craquage se produisent simultanément ;
 f) recyclage des produits d'hydroconversion lourds (31 ; 3 ; 16) de l'unité d'hydroconversion (25) provenant de l'étape e) avec un point d'ébullition au-dessus de 370 °C vers l'unité d'hydrocraquage (4) dans l'étape a) ou tant vers l'unité d'hydrocraquage (4) que vers l'unité de craquage catalytique (17) dans l'étape c) ; et
 g) alimentation d'au moins une portion (13) du premier résidu (12) d'hydrocarbures lourds provenant de l'étape b) dans l'unité d'hydroconversion (25) dans l'étape e).

2. Processus selon la revendication 1, dans lequel les produits d'hydroconversion lourds (31 ; 3 ; 16) de l'unité d'hydroconversion (25) provenant de l'étape e) sont plus lourds que du diesel et ont un point d'ébullition qui est égal ou inférieur à 620 °C.

3. Processus selon la revendication 1 ou 2, dans lequel dans le cas de formation de coke dans l'étape e), les produits d'hydroconversion lourds (31 ; 3 ; 16) de l'unité d'hydroconversion (25) qui sont plus lourds que du diesel subissent une décokéfaction avant d'être recyclés vers l'unité d'hydrocraquage (4) dans l'étape a) ou tant vers l'unité d'hydrocraquage (4) dans l'étape a) que vers l'unité de craquage catalytique (17).

4. Processus selon l'une quelconque des revendications précédentes, dans lequel une portion (14) du premier résidu (12) d'hydrocarbures lourds de l'unité d'hydrocraquage (4) provenant de l'étape b) est envoyée à l'unité de craquage catalytique (17).

5. Processus selon l'une quelconque des revendications précédentes, dans lequel une portion (2) du premier résidu (12) d'hydrocarbures lourds de l'unité d'hydrocraquage (4) provenant de l'étape b) est recyclée vers l'unité d'hydrocraquage (4).

6. Processus selon l'une quelconque des revendications précédentes, dans lequel le rapport du flot de recyclage (16) de produits d'hydroconversion lourds de l'unité d'hydroconversion (25) provenant de l'étape e) vers l'unité de craquage catalytique (17) sur le flot de recyclage (3) de produits d'hydroconversion lourds de l'unité d'hydroconversion (25) provenant de l'étape e) vers l'unité d'hydrocraquage (4) est dans la plage comprise entre 0 et 0,99.

7. Processus selon la revendication 6, dans lequel le rapport du flot de recyclage de produits d'hydroconversion lourds de l'unité d'hydroconversion (25) provenant de l'étape e) vers l'unité de craquage catalytique (17) sur le flot de recyclage de produits d'hydroconversion lourds de l'unité d'hydroconversion (25) provenant de l'étape e) vers l'unité d'hydrocraquage (4) est de préférence dans la plage comprise entre 0,1 et 0,3 et plus de préférence dans la plage comprise entre 0,13 et 0,16.

8. Processus selon l'une quelconque des revendications précédentes, dans lequel le premier résidu (12) d'hydrocarbures lourds provenant de l'étape b) a un point d'ébullition au-dessus de 390 °C.

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9. Processus selon l'une quelconque des revendications précédentes, dans lequel le second résidu (23) d'hydrocarbures lourds provenant de l'étape d) consiste principalement en huile de recyclage clarifiée (CSO) avec un point d'ébullition au-dessus de 370 °C.

5 10. Processus selon l'une quelconque des revendications précédentes, dans lequel des produits (18) de l'unité de craquage catalytique (17) sont distillés dans une tour de distillation (19) et dans lequel du kérosène et du diesel sont produits à partir de distillats moyens ou d'huile de recyclage légère (LCO) de la tour de distillation (19) avec un point d'ébullition dans la plage comprise entre 180 °C et 370 °C.

10 11. Processus selon l'une quelconque des revendications précédentes, dans lequel des produits (5) de l'unité d'hydrocraquage (4) sont distillés dans une tour de distillation (6) afin de produire du kérosène (10) avec un point d'ébullition dans la plage comprise entre 160 et 290 °C et du diesel d'hydrocraquage avec un point d'ébullition dans la plage comprise entre 290 °C et 390 °C.

15 12. Processus selon l'une quelconque des revendications précédentes, dans lequel le rapport du flot de recyclage de produits d'hydroconversion lourds de l'unité d'hydroconversion (25) provenant de l'étape e) vers l'unité de craquage catalytique (17) sur le flot de recyclage de produits d'hydroconversion lourds de l'unité d'hydroconversion (25) provenant de l'étape e) vers l'unité d'hydrocraquage (4) est dans la plage comprise entre 0,13 et 0,16.

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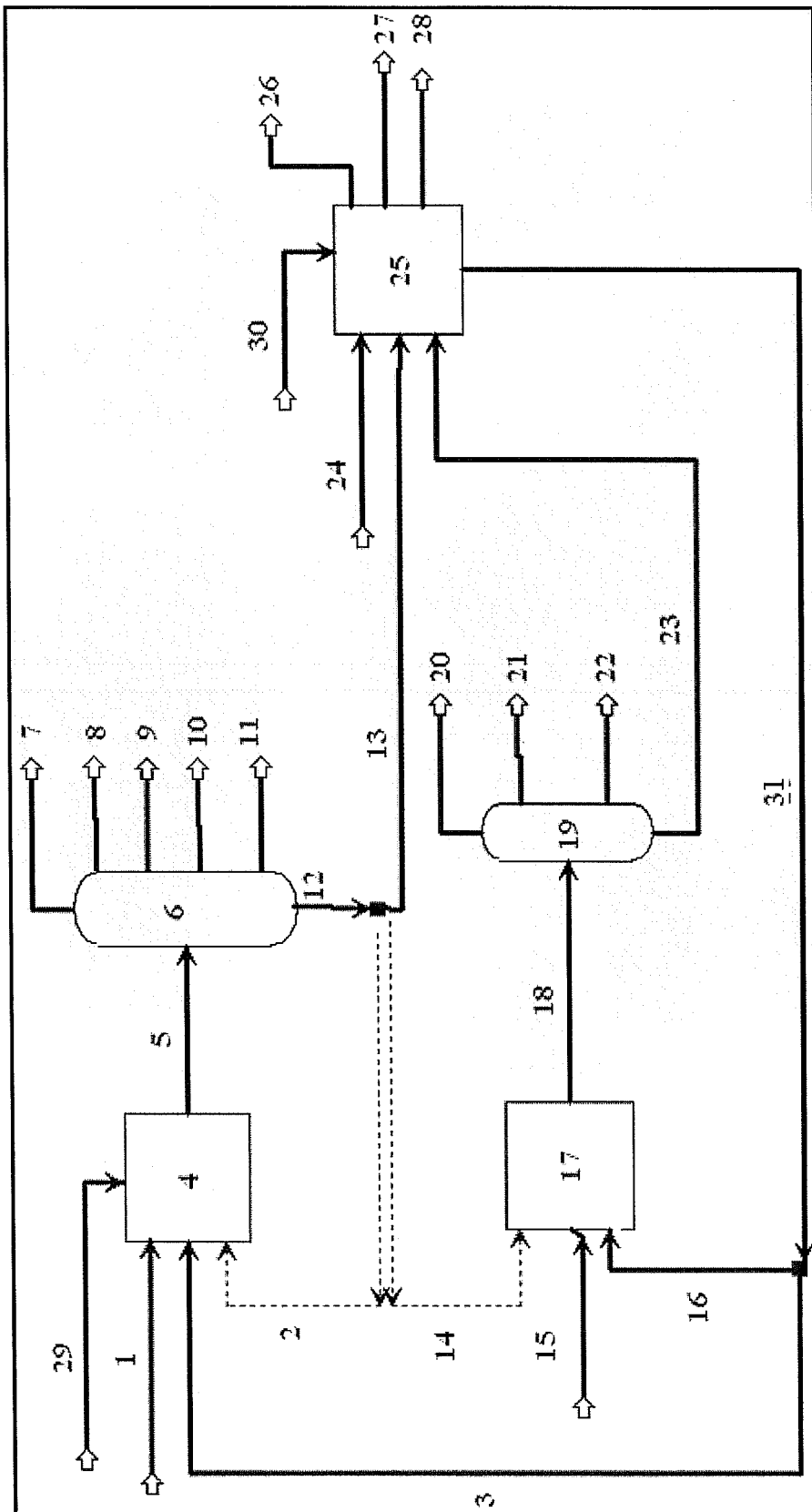


Fig. 1

REFERENCES CITED IN THE DESCRIPTION

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