

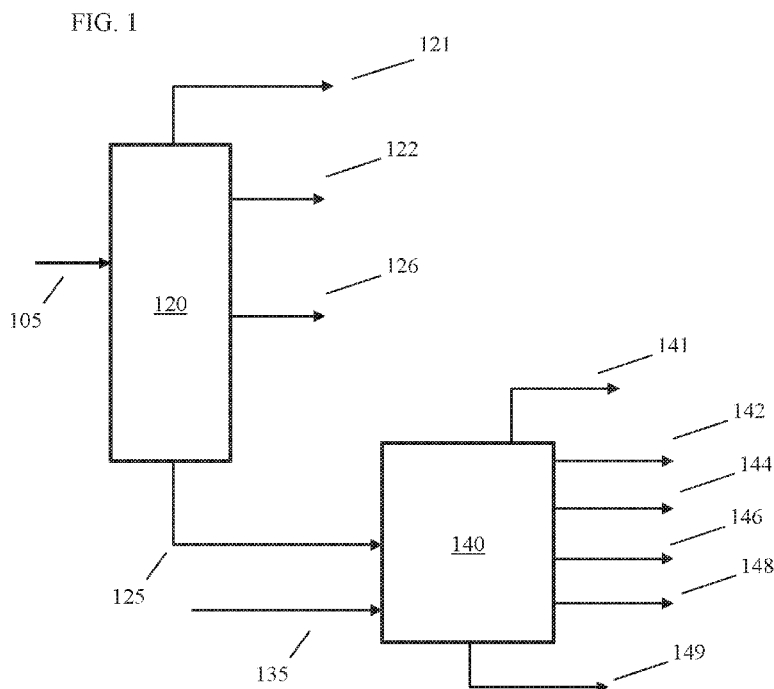


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- (71) Applicant: EXXONMOBIL RESEARCH AND ENGINEERING COMPANY [US/US]; 1545 Route 22 East, P.O. Box 900, Annandale, NY 08801-0900 (US).
- (72) Inventor: COOPER, Ashley, E.; 3803 Oreana Court, Spring, TX 77386 (US).
- (74) Agents: GUICE, Chad, A. et al.; ExxonMobil Research and Engineering Company, 1545 Route 22 East, P.O. box 900, Annandale, NJ 08801-0900 (US).

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[Continued on next page]

- (54) Title: FLUID CATALYTIC CRACKING OF TIGHT OIL RESID



- (57) Abstract: Methods are provided for FCC processing of atmospheric resid boiling range feedstocks derived from tight oils. Due to low contents of metals, sulfur, and/or coke-forming compounds, an atmospheric resid boiling range fraction derived from a tight oil feedstock that includes a substantial 1050°F+ (566°C+) portion can be suitable for processing in an FCC reactor. This can allow the atmospheric resid boiling range portion of a tight oil feedstock to be processed in an FCC reactor without requiring a vacuum distillation.

**Declarations under Rule 4.17:**

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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**FLUID CATALYTIC CRACKING OF TIGHT OIL RESID****FIELD**

**[0001]** Systems and methods are provided for processing of tight oil fractions.

**BACKGROUND**

**[0002]** Fluid catalytic cracking (FCC) processes are commonly used in refineries as a method for converting heavy oil feedstocks, without requiring additional hydrogen, to produce lower boiling fractions suitable for use as fuels. FCC processes can be valuable for converting vacuum gas oil boiling range feeds to lower boiling compounds suitable for use as naphtha or distillate fuels while avoiding excessive consumption of hydrogen. However, the catalysts used for FCC processes are typically susceptible to metal poisoning. To avoid exposing FCC catalysts to excessive metal contents, vacuum fractionation can be used to remove a vacuum resid fraction from a heavy oil feedstock prior to FCC processing.

**[0003]** U.S. Patent 8,007,662 describes methods for direct feed / effluent heat exchange in fluid catalytic cracking. The methods are described as being suitable for FCC processing of feeds having reduced quantities of coke precursors. Suitable feeds are described as having a total metals content of less than about 5 wppm, a Conradson Carbon residue of less than about 3 wt%, and a sulfur content of less than about 500 wppm.

**SUMMARY**

**[0004]** In an aspect, a method is provided for processing a tight oil fraction, the method including separating a tight oil fraction at a pressure of at least 5 psig (35 kPa) to form at least a higher boiling fraction having a T5 boiling point of at least about 650°F (343°C) and a second fraction having a lower T5 boiling point than the higher boiling fraction, the higher boiling fraction comprising about 5 wppm to about 10 wppm of metals and at least about 20 wt% of 1050°F+ compounds; and exposing the higher boiling fraction to a cracking catalyst under effective fluid catalytic cracking conditions to form a cracked effluent comprising at least about 5 wt% of 1050°F+ compounds, or at least about 10 wt%.

**[0005]** In another aspect, a fluid catalytic cracking effluent is provided, the fluid catalytic cracking effluent comprising a light catalytic naphtha fraction, a heavy catalytic naphtha fraction, a light cycle oil, and a main column bottoms, the light catalytic naphtha fraction having a research octane number of at least 90 (or at least 93) and an olefin content of at least 35 wt% (or at least 40 wt%), the heavy catalytic naphtha having a research octane number of at least 90 (or at least 92) and optionally an olefin content of at least 6 wt% (or at least 8 wt% or at least 9 wt%), the light cycle oil having a cetane index of at least 20.0, and the main column bottoms optionally having an API gravity of at least -10, or at least -9.

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**BRIEF DESCRIPTION OF THE FIGURES**

**[0006]** FIG. 1 shows a configuration suitable for performing a fluid catalytic cracking process on a tight oil fraction.

**[0007]** FIG. 2 shows examples of properties of fluid catalytic cracking effluents.

**DETAILED DESCRIPTION**

**[0008]** Shale oil or “tight oil” represents an increasingly important source of crude oil. It has been determined that tight oils can have a somewhat different compositional profile in comparison with conventional mineral crude oils. In particular, the heavier (higher boiling) portions of a tight oil can tend to have lower sulfur contents and/or lower total metals contents than other mineral crude oils.

**[0009]** In various aspects, systems and methods are provided for FCC processing of atmospheric resid boiling range feedstocks derived from tight oils. Due to low contents of metals, sulfur, and/or coke-forming compounds, an atmospheric resid boiling range fraction derived from a tight oil feedstock that includes a substantial 1050°F+ (566°C+) portion can be suitable for processing in an FCC reactor. A substantial 1050°F+ (566°C) portion can correspond to an atmospheric resid boiling range fraction having at least 15 wt% of 1050°F+ compounds, or at least about 20 wt%, or at least about 25 wt%, or at least about 30 wt%, such as up to about 40 wt%. This can allow the atmospheric resid boiling range portion of a tight oil feedstock to be processed in an FCC reactor without requiring a vacuum distillation. Instead, a tight oil fraction can be topped, such as by separation in an atmospheric tower, a flash tower, or a flash drum, to form one or more fuels boiling range fractions and a bottoms fraction. The one or more fuels boiling range fractions can include naphtha, kerosene, and/or diesel boiling range fractions. By separating such fuels boiling range fractions prior to FCC processing, further cracking of these fuels boiling range fractions to lower value products can be reduced or minimized. The bottoms fraction remaining after separation of fuels boiling range fractions, such as a 650°F+ (343°C+) fraction, can be processed in an FCC reactor.

**[0010]** One of the difficulties with processing feeds using FCC processing is the accumulation of metals on the FCC catalyst. Crude oil sources that include distillate boiling range compounds also typically include vacuum resid boiling range compounds. Unfortunately, mineral sources of vacuum resid fractions also typically contain metals such as nickel and vanadium. Such metals can accumulate on an FCC catalyst and can cause deactivation. In order to reduce or minimize the rate of deactivation under conventional methods, the vacuum resid portion of a feed can be separated from the distillate portion by vacuum distillation. The fractionation cut point in such a

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separation can be selected to achieve a desired target metals content in the resulting distillate portion. Typical target metals contents for FCC feeds are 2 – 3 wppm.

**[0011]** Crude oils derived from shale oil or tight oil sources can have an atmospheric resid boiling range fraction that includes both a distillate and a 1050°F+ (566°C) or vacuum resid portion, similar to other mineral sources. However, it has been determined that the 1050°F+ portion of atmospheric resids derived from a tight oil sources can have unexpectedly low metal contents. The unexpectedly low metal contents can correspond to metal contents for an atmospheric resid boiling range fraction of about 5 wppm to about 15 wppm, or about 5 wppm to about 10 wppm, or about 5 wppm to about 7 wppm. Additionally or alternately, an atmospheric resid boiling range fraction can have a combined content of Ni, Cr, and/or V of about 5 wppm to about 15 wppm, or about 5 wppm to about 10 wppm, or about 5 wppm to about 7 wppm. While the metal content of a 1050°F+ portion of a feed derived from tight oil sources is higher than the feedstock metals content for conventional FCC processing, it has been determined that 1050°F+ portion of a feed derived from tight oil sources can be suitable for FCC processing.

**[0012]** Because the 1050°F+ portion of a feed derived from a tight oil can be suitable for FCC processing, a crude oil derived from tight oil can be prepared for FCC processing using atmospheric distillation, as opposed to using both an atmospheric distillation and a vacuum distillation. Performing an atmospheric distillation can allow fuels boiling range compounds to be removed from the feed prior to FCC processing. This can avoid cracking of diesel boiling range compounds to naphtha and/or cracking of naphtha to light ends.

**[0013]** In some aspects, an atmospheric distillation can be tightly controlled in order to increase the amount of diesel boiling range compounds that are separated out prior to FCC processing. Alternatively, another type of distillation or fractionation technique could be used instead of an atmospheric distillation, such as a flash fractionation. A flash fractionation can tend to produce a wider overlap in boiling range between the two resulting fractions as compared with performing a distillation in a distillation column or tower. Depending on the nature of the fractionation, the fractionation can be performed at a pressure of about 5 psig (35 kPa) to about 30 psig (207 kPa). This is in contrast to a vacuum fraction, which can typically be performed at a pressure of about 2 psig (about 15 kPa) or less. Depending on the nature of the fractionation, the fractionation can be used to form a higher boiling fraction having a T10 boiling point of about 700°F (371°C) or less, or about 650°F (343°C) or less, or 600°F (316°C) or less; a T5 boiling point of about 700°F (371°C) or less, or about 650°F (343°C) or less, or 600°F (316°C) or less; and/or a T2 boiling point of about 700°F (371°C) or less, or about 650°F (343°C) or less, or 600°F (316°C) or less. The higher boiling fraction, or at least a portion of it, corresponds to a tight oil atmospheric resid that can be processed

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in an FCC reactor. The boiling points for the higher boiling fraction can be determined by a suitable ASTM method, such as ASTM D2887.

**[0014]** Another option for characterizing the separation of a tight oil into (at least) a lower boiling fraction and a higher boiling fraction can be based on the boiling range of the lower boiling fraction. In some aspects, it can be desirable to increase or maximize the amount of diesel boiling range compounds in the lower boiling fraction. This can be accomplished by performing a fractionation to form a lower boiling fraction having a T90 boiling point of about 650°F (343°C) or less, or about 690°F (365°C) or less, as determined by ASTM D86.

**[0015]** In this discussion, a tight oil or tight oil fraction is defined in accordance with the U.S. Energy Information Administration definition, which defines a tight oil as a mineral crude oil or crude oil fraction that is extracted from formations that must be hydraulically fractured to produce oil at a commercial rate. In this discussion, production of oil at a commercial rate is defined as at least 100 barrels per day, but in some aspects a lower threshold of 10 barrels per day can be used. A tight oil fraction is defined to include the limiting case of a fraction that corresponds to a whole tight oil crude.

**[0016]** In some aspects, reference is made to conversion of a feedstock relative to a conversion temperature T. Conversion relative to a temperature T is defined based on the portion of the feedstock that boils at a temperature greater than the conversion temperature T. The amount of conversion during a process (or optionally across multiple processes) is defined as the weight percentage of the feedstock that is converted from boiling at a temperature above the conversion temperature T to boiling at a temperature below the conversion temperature T. As an illustrative hypothetical example, consider a feedstock that includes 40 wt% of components that boil at 700°F (371°C) or greater. By definition, the remaining 60 wt% of the feedstock boils at less than 700°F (371°C). For such a feedstock, the amount of conversion relative to a conversion temperature of 700°F (371°C) would be based only on the 40 wt% that initially boils at 700°F (371°C) or greater. If such a feedstock is exposed to a process with 30% conversion relative to a 700°F (371°C) conversion temperature, the resulting product would include 72 wt% of components boiling below 700°F (371°C) and 28 wt% of components boiling above 700°F (371°C).

**[0017]** In various aspects of the invention, reference may be made to one or more types of fractions generated during distillation of a petroleum feedstock. Such fractions may include naphtha fractions, kerosene fractions, diesel fractions, vacuum gas oil or distillate fractions, and atmospheric resid fractions. Each of these types of fractions can be defined based on a boiling range, such as a boiling range that includes at least 90 wt% of the fraction, or at least 95 wt% of the fraction. For example, for many types of naphtha fractions, at least 90 wt% of the fraction, and

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preferably at least 95 wt%, can have a boiling point in the range of 85°F (29°C) to 350°F (177°C). For some heavier naphtha fractions, at least 90 wt% of the fraction, and preferably at least 95 wt%, can have a boiling point in the range of 85°F (29°C) to 400°F (204°C). For a kerosene fraction, at least 90 wt% of the fraction, and preferably at least 95 wt%, can have a boiling point in the range of 300°F (149°C) to 600°F (288°C). Alternatively, for a kerosene fraction targeted for some uses, such as jet fuel production, at least 90 wt% of the fraction, and preferably at least 95 wt%, can have a boiling point in the range of 300°F (149°C) to 550°F (288°C). For a diesel fraction, at least 90 wt% of the fraction, and preferably at least 95 wt%, can have a boiling point in the range of 400°F (204°C) to 750°F (399°C). For a (vacuum) gas oil fraction, at least 90 wt% of the fraction, and preferably at least 95 wt%, can have a boiling point in the range of 650°F (343°C) to 1100°F (593°C). Optionally, for some gas oil fractions, a narrower boiling range may be desirable. For such gas oil fractions, at least 90 wt% of the fraction, and preferably at least 95 wt%, can have a boiling point in the range of 650°F (343°C) to 1000°F (538°C), or 650°F (343°C) to about 900°F (482°C). For an atmospheric resid boiling range fraction, the lower end of the boiling range can be similar to a vacuum gas oil. This can correspond to having a T5 boiling point of at least about 600°F (316°C), or at least about 650°F (343°C), or at least about 700°F (371°C). Such a T5 boiling point can be measured by a suitable method, such as ASTM D2887. An atmospheric resid boiling range fraction is different from a vacuum gas oil fraction due to the lack of a well-defined T95 boiling point and/or final boiling point. Instead, an atmospheric resid boiling range fraction can also include higher boiling point compounds, such as 1050°F+ compounds.

#### Feedstock – Tight Oil Atmospheric Resid

**[0018]** A tight oil atmospheric resid can correspond to a high boiling fraction, such as a bottoms fraction, from an atmospheric distillation or other type of fractionation as described above. A variety of properties of a tight oil fraction and/or a tight oil atmospheric resid boiling range fraction can be characterized to specify the nature of the fraction.

**[0019]** Crude oil produced from shale rock formations using hydraulic fracturing (i.e., a tight oil) can generally be light, such as greater than 35°API gravity. Such crude oil can also generally have a sulfur content of less than about 0.5 wt%.

**[0020]** After fractionation to remove diesel fuel boiling range and lower boiling compounds, an atmospheric resid fraction (or other similar boiling range fraction) derived from a tight oil can include a 1050°F+ (566°C) portion corresponding to at least about 15 wt% of the atmospheric resid fraction, or at least about 20 wt%, or at least about 25 wt%, or at least about 30 wt%. Based in part on the increased amount of 1050°F+ compounds, a tight oil atmospheric resid fraction can also have an increased content of Conradson Carbon Residue (CCR) relative to a conventional feed for

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FCC processing. In various aspects, a tight oil atmospheric resid boiling range fraction can have a CCR content of at least about 2 wt%, or at least about 5 wt%, or at least about 8 wt%, or at least about 10 wt%.

**[0021]** Density, or weight per volume, of an atmospheric resid boiling range fraction derived from a tight oil can also be characterized. In various aspects, the density of the atmospheric resid boiling range fraction at 60°F can be 0.88 g/cc to 0.98 g/cc, or 0.89 g/cc to 0.98 g/cc, or 0.88 g/cc to 0.97 g/cc, or 0.89 g/cc to 0.97 g/cc.

**[0022]** Contaminants such as nitrogen and sulfur are typically found in an atmospheric resid boiling range fraction, often in organically-bound form. Nitrogen content can range from about 50 wppm to about 3000 wppm elemental nitrogen, or about 75 wppm to about 2000 wppm, or about 100 wppm to about 1000 wppm elemental nitrogen, or about 250 wppm to about 500 wppm, based on total weight of the atmospheric resid boiling range fraction. The nitrogen containing compounds can be present as basic or non-basic nitrogen species. Examples of nitrogen species can include quinolones, substituted quinolones, carbazoles, and substituted carbazoles.

**[0023]** The sulfur content of an atmospheric resid boiling range fraction can be at least about 200 wppm elemental sulfur, based on total weight of the atmospheric resid boiling range fraction. Generally, the sulfur content of a atmospheric resid boiling range fraction can range from about 200 wppm to about 20,000 wppm elemental sulfur based on total weight of the heavy component, or from about 200 wppm to about 10,000 wppm, or from about 200 wppm to about 5,000 wppm, or from about 200 wppm to about 4,000 wppm, or from about 200 wppm to about 3,000 wppm, or from about 500 wppm to about 20,000 wppm, or from about 500 wppm to about 10,000 wppm, or from about 500 wppm to about 5,000 wppm, or from about 500 wppm to about 4,000 wppm, or from about 500 wppm to about 3,000 wppm, or from about 1,000 wppm to about 20,000 wppm, or from about 1,000 wppm to about 10,000 wppm, or from about 1,000 wppm to about 5,000 wppm, or from about 1,000 wppm to about 4,000 wppm, or from about 1,000 wppm to about 3,000 wppm. Sulfur can usually be present as organically bound sulfur. Examples of such sulfur compounds include the class of heterocyclic sulfur compounds such as thiophenes, tetrahydrothiophenes, benzothiophenes and their higher homologs and analogs. Other organically bound sulfur compounds include aliphatic, naphthenic, and aromatic mercaptans, sulfides, di- and polysulfides.

#### FCC Processing

**[0024]** In various aspects, at least a portion of a tight oil atmospheric resid can be used as a feed for processing in a Fluid Catalytic Cracking ("FCC") unit. The tight oil atmospheric resid can be processed alone in the FCC process, or the hydrotreated effluent can be combined with another



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suitable feed for processing in an FCC process. Such other suitable feedstreams can include feeds (such as gas oils or distillates) boiling in the range of about 430°F to about 1050°F (221 to 566°C). The FCC feed may also comprise recycled hydrocarbons, such as light or heavy cycle oils.

**[0025]** An example of a suitable reactor for performing an FCC process can be a riser reactor. Within the reactor riser, the FCC feedstream can be contacted with a catalytic cracking catalyst under cracking conditions thereby resulting in spent catalyst particles containing carbon deposited thereon and a lower boiling product stream. The cracking conditions can typically include: temperatures from about 900 to about 1060°F (482 to 571°C.), or about 950 to about 1040°F (510 to 560°C); hydrocarbon partial pressures from about 10 to 50 psia (70-345 kPa), or from about 20 to 40 psia (140-275 kPa); and a catalyst to feed (wt/wt) ratio from about 3 to 8, or about 5 to 6, where the catalyst weight is total weight of the catalyst composite. Steam may be concurrently introduced with the feed into the reaction zone. The steam may comprise up to about 5 wt% of the feed. In some aspects, the FCC feed residence time in the reaction zone is less than about 5 seconds, or from about 3 to 5 seconds, or from about 2 to 3 seconds.

**[0026]** Catalysts suitable for use within the FCC reactor herein are fluid cracking catalysts comprising either a large-pore molecular sieve or a mixture of at least one large-pore molecular sieve catalyst and at least one medium-pore molecular sieve catalyst. Large-pore molecular sieves suitable for use herein can be any molecular sieve catalyst having an average pore diameter greater than 0.7 nm which are typically used to catalytically "crack" hydrocarbon feeds. In various aspects, both the large-pore molecular sieves and the medium-pore molecular sieves used herein may be selected from those molecular sieves having a crystalline tetrahedral framework oxide component. For example, the crystalline tetrahedral framework oxide component can be selected from the group consisting of zeolites, tectosilicates, tetrahedral aluminophosphates (ALPOs) and tetrahedral silicoaluminophosphates (SAPOs). Preferably, the crystalline framework oxide component of both the large-pore and medium-pore catalyst is a zeolite. It should be noted that when the cracking catalyst comprises a mixture of at least one large-pore molecular sieve catalyst and at least one medium-pore molecular sieve, the large-pore component is typically used to catalyze the breakdown of primary products from the catalytic cracking reaction into clean products such as naphtha and distillates for fuels and olefins for chemical feedstocks.

**[0027]** Large pore molecular sieves that are typically used in commercial FCC process units are also suitable for use herein. FCC units used commercially generally employ conventional cracking catalysts which include large-pore zeolites such as USY or REY. Additional large pore molecular sieves that can be employed in accordance with the present invention include both natural and synthetic large pore zeolites. Non-limiting examples of natural large-pore zeolites

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include gmelinite, chabazite, dachiardite, clinoptilolite, faujasite, heulandite, analcite, levynite, erionite, sodalite, cancrinite, nepheline, lazurite, scolecite, natrolite, offretite, mesolite, mordenite, brewsterite, and ferrierite. Non-limiting examples of synthetic large pore zeolites are zeolites X, Y, A, L, ZK-4, ZK-5, B, E, F, H, J, M, Q, T, W, Z, alpha and beta, omega, REY and USY zeolites. In some aspects, the large pore molecular sieves used herein can be selected from large pore zeolites. In such aspects, suitable large-pore zeolites for use herein can be the faujasites, particularly zeolite Y, USY, and REY.

**[0028]** Medium-pore size molecular sieves that are suitable for use herein include both medium pore zeolites and silicoaluminophosphates (SAPOs). Medium pore zeolites suitable for use in the practice of the present invention are described in "Atlas of Zeolite Structure Types", eds. W. H. Meier and D. H. Olson, Butterworth-Heinemann, Third Edition, 1992, which is hereby incorporated by reference. The medium-pore size zeolites generally have an average pore diameter less than about 0.7 nm, typically from about 0.5 to about 0.7 nm and includes for example, MFI, MFS, MEL, MTW, EUO, MTT, HEU, FER, and TON structure type zeolites (IUPAC Commission of Zeolite Nomenclature). Non-limiting examples of such medium-pore size zeolites, include ZSM-5, ZSM-12, ZSM-22, ZSM-23, ZSM-34, ZSM-35, ZSM-38, ZSM-48, ZSM-50, silicalite, and silicalite 2. An example of a suitable medium pore zeolite is ZSM-5, which is described in U.S. Pat. Nos. 3,702,886 and 3,770,614. Other suitable zeolites can include ZSM-11, described in U.S. Pat. No. 3,709,979; ZSM-12 in U.S. Pat. No. 3,832,449; ZSM-21 and ZSM-38 in U.S. Pat. No. 3,948,758; ZSM-23 in U.S. Pat. No. 4,076,842; and ZSM-35 in U.S. Pat. No. 4,016,245. As mentioned above SAPOs, such as SAPO-11, SAPO-34, SAPO-41, and SAPO-42, which are described in U.S. Pat. No. 4,440,871 can also be used herein. Non-limiting examples of other medium pore molecular sieves that can be used herein are chromosilicates; gallium silicates; iron silicates; aluminum phosphates (ALPO), such as ALPO-11 described in U.S. Pat. No. 4,310,440; titanium aluminosilicates (TASO), such as TASO-45 described in EP-A No. 229,295; boron silicates, described in U.S. Pat. No. 4,254,297; titanium aluminophosphates (TAPO), such as TAPO-11 described in U.S. Pat. No. 4,500,651 and iron aluminosilicates. All of the above patents are incorporated herein by reference.

**[0029]** The medium-pore size zeolites used herein can also include "crystalline admixtures" which are thought to be the result of faults occurring within the crystal or crystalline area during the synthesis of the zeolites. Examples of crystalline admixtures of ZSM-5 and ZSM-11 are disclosed in U.S. Pat. No. 4,229,424 which is incorporated herein by reference. The crystalline admixtures are themselves medium-pore size zeolites and are not to be confused with physical

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admixtures of zeolites in which distinct crystals of crystallites of different zeolites are physically present in the same catalyst composite or hydrothermal reaction mixtures,

**[0030]** In some aspects, the large-pore zeolite catalysts and/or the medium-pore zeolite catalysts can be present as "self-bound" catalysts, where the catalyst does not include a separate binder. In other aspects, the large-pore and medium-pore catalysts can be present in an inorganic oxide matrix component that binds the catalyst components together so that the catalyst product is hard enough to survive inter-particle and reactor wall collisions. The inorganic oxide matrix can be made from an inorganic oxide sol or gel which is dried to "glue" the catalyst components together. Preferably, the inorganic oxide matrix can be comprised of oxides of silicon and aluminum. It is also preferred that separate alumina phases be incorporated into the inorganic oxide matrix. Species of aluminum oxyhydroxides- $\gamma$ -alumina, boehmite, diaspore, and transitional aluminas such as  $\alpha$ -alumina,  $\beta$ -alumina,  $\gamma$ -alumina,  $\delta$ -alumina,  $\epsilon$ -alumina,  $\kappa$ -alumina, and  $\rho$ -alumina can be employed. Preferably, the alumina species is an aluminum trihydroxide such as gibbsite, bayerite, nordstrandite, or doyleite. The matrix material may also contain phosphorous or aluminum phosphate. Optionally, the large-pore catalysts and medium-pore catalysts be present in the same or different catalyst particles, in the aforesaid inorganic oxide matrix.

**[0031]** In the FCC reactor, the cracked FCC product is removed from the fluidized catalyst particles. Preferably this is done with mechanical separation devices, such as an FCC cyclone. The FCC product is removed from the reactor via an overhead line, cooled and sent to a fractionator tower for separation into various cracked hydrocarbon product streams. These product streams may include, but are not limited to, a light gas stream (generally comprising C<sub>4</sub> and lighter hydrocarbon materials), a naphtha (gasoline) stream, a distillate (diesel and/or jet fuel) stream, and other various heavier gas oil product streams. The other heavier stream or streams can include a bottoms stream.

**[0032]** In the FCC reactor, after removing most of the cracked FCC product through mechanical means, the majority of, and preferably substantially all of, the spent catalyst particles are conducted to a stripping zone within the FCC reactor. The stripping zone will typically contain a dense bed (or "dense phase") of catalyst particles where stripping of volatiles takes place by use of a stripping agent such as steam. There will also be space above the stripping zone wherein the catalyst density is substantially lower and which space can be referred to as a "dilute phase". This dilute phase can be thought of as either a dilute phase of the reactor or stripper in that it will typically be at the bottom of the reactor leading to the stripper.

**[0033]** The majority of, and preferably substantially all of, the stripped catalyst particles are subsequently conducted to a regeneration zone wherein the spent catalyst particles are regenerated

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by burning coke from the spent catalyst particles in the presence of an oxygen containing gas, preferably air thus producing regenerated catalyst particles. This regeneration step restores catalyst activity and simultaneously heats the catalyst to a temperature from about 1200°F to about 1400°F (649 to 760°C). The majority of, and preferably substantially all of the hot regenerated catalyst particles can then be recycled to the FCC reaction zone where they contact injected FCC feed.

**[0034]** It is noted that the CCR content of an atmospheric resid boiling range fraction can be higher than a typical FCC feed due to the presence of a substantial portion of 1050°F+ compounds. This can cause coke to form at an increased rate. At conventional catalyst circulation rates, this could lead to increased temperatures during regeneration due to the additional amount of coke present on the catalyst. In various aspects, the increased temperature in the regeneration zone can be mitigated at least in part by increasing the catalyst replacement rate. Introduction of fresh catalyst at a lower temperature can reduce the overall temperature of catalyst introduced into the FCC reactor.

#### Hydrotreatment of FCC Effluent Portions

**[0035]** After FCC processing, one or more resulting naphtha boiling range fractions, diesel boiling range fractions, and/or distillate boiling range fractions can be separated from the FCC effluent. These types of fractions can sometimes be referred to as catalytic naphtha and various cycle oils, such as light catalytic cycle oil or heavy catalytic cycle oil. The one or more naphtha and/or diesel boiling range fractions can be hydrotreated to meet desired sulfur content targets.

**[0036]** In various aspects, a naphtha boiling range portion of an FCC effluent can be hydrotreated (sometimes referred to as hydrodesulfurized) to reduce the sulfur content of the higher boiling portion. Such a hydrodesulfurization process can correspond to a selective or a non-selective hydrodesulfurization process. A selective hydrodesulfurization process can refer to a process where the hydrotreatment catalyst and/or the hydrotreatment conditions are selected based on a desire to preserve the olefin content of the hydrotreated product. A non-selective hydrodesulfurization process can refer to a process where a substantial portion of the olefins present in an naphtha feed are saturated during hydrodesulfurization. While a selective hydrodesulfurization process can be used to treat the higher boiling portion, it is not necessary.

**[0037]** A (optionally selective) hydrodesulfurization process can be performed in any suitable reaction system. The hydrodesulfurization can be performed in one or more fixed bed reactors, each of which can comprise one or more catalyst beds of the same, or different, hydrodesulfurization catalyst. Optionally, more than one type of catalyst can be used in a single bed. Although other types of catalyst beds can be used, fixed beds are preferred. Non-limiting examples of such other types of catalyst beds that may be used in the practice of the present

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invention include fluidized beds, ebullating beds, slurry beds, and moving beds. Interstage cooling between reactors, or between catalyst beds in the same reactor, can be employed since some olefin saturation can take place, and olefin saturation as well as the desulfurization reaction are generally exothermic. A portion of the heat generated during hydrodesulfurization can be recovered by conventional techniques. Where this heat recovery option is not available, conventional cooling may be performed through cooling utilities such as cooling water or air, or by use of a hydrogen quench stream. In this manner, optimum reaction temperatures can be more easily maintained.

**[0038]** In various aspects, suitable (optionally selective) hydrodesulfurization catalysts include catalysts that are comprised of at least one Group VIII metal oxide, preferably an oxide of a metal selected from selected from Co and/or Ni, more preferably Co; and at least one Group VI metal oxide, preferably an oxide of a metal selected from Mo and W, more preferably Mo, on a support material, such as silica or alumina. Other suitable hydrotreating catalysts include zeolitic catalysts, as well as noble metal catalysts where the noble metal is selected from Pd and Pt. It is within the scope of the present invention that more than one type of hydrotreating catalyst be used in the same reaction vessel. The Group VIII metal oxide of a selective hydrodesulfurization catalyst can be present in an amount ranging from about 0.1 to about 20 wt. %, preferably from about 1 to about 12%. The Group VI metal oxide can be present in an amount ranging from about 1 to about 50 wt. %, preferably from about 2 to about 20 wt. %. All metal oxide weight percents are on support. By "on support" we mean that the percents are based on the weight of the support. For example, if the support were to weigh 100 g. then 20 wt. % Group VIII metal oxide would mean that 20 g. of Group VIII metal oxide is on the support.

**[0039]** The hydrodesulfurization catalysts can be supported catalysts. Any suitable refractory catalyst support material, such as inorganic oxide support materials, can be used as supports for the catalyst of the present invention. Non-limiting examples of suitable support materials include: zeolites, alumina, silica, titania, calcium oxide, strontium oxide, barium oxide, carbons, zirconia, magnesia, diatomaceous earth, lanthanide oxides including cerium oxide, lanthanum oxide, neodymium oxide, yttrium oxide, and praseodymium oxide; chromia, thorium oxide, urania, niobia, tantalum, tin oxide, zinc oxide, and aluminum phosphate. Preferred are alumina, silica, and silica-alumina. It is to be understood that the support material can also contain small amounts of contaminants, such as Fe, sulfates, silica, and various metal oxides that can be introduced during the preparation of the support material. These contaminants are present in the raw materials used to prepare the support and will preferably be present in amounts less than about 1 wt. %, based on the total weight of the support. It is more preferred that the support material be substantially free of such contaminants. In another embodiment, about 0 to about 5 wt. %, preferably from about

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0.5 to about 4 wt. %, and more preferably from about 1 to about 3 wt. % of an additive can be present in the support, which additive is selected from the group consisting of phosphorus and metals or metal oxides from Group IA (alkali metals) of the Periodic Table of the Elements.

**[0040]** Generally, (optionally selective) hydrodesulfurization conditions can include temperatures from about 425°F (218°C) to about 800°F (427°C), or about 500°F (260°C) to about 675°F (357°C). Other (optionally selective) hydrodesulfurization conditions can include a pressure of from about 60 psig (414 kPa) to about 800 psig (5516 kPa), preferably from about 200 psig (1379 kPa) to about 500 psig (3447 kPa), more preferably from about 250 psig (1724 kPa) to about 400 psig (2758 kPa). The hydrogen feed rate can be from about 500 standard cubic feet per barrel (scf/b) (84.2 m<sup>3</sup>/m<sup>3</sup>) to about 6000 scf/b (1011 m<sup>3</sup>/m<sup>3</sup>), preferably from about 1000 scf/b (168.5 m<sup>3</sup>/m<sup>3</sup>) to about 3000 scf/b (505.5 m<sup>3</sup>/m<sup>3</sup>). The liquid hourly space velocity can be from about of about 0.5 hr<sup>-1</sup> to about 15 hr<sup>-1</sup>, preferably from about 0.5 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>, more preferably from about 1 hr<sup>-1</sup> to about 5 hr<sup>-1</sup>.

**[0041]** In various aspects, a goal of a (optionally selective) hydrodesulfurization process can be to produce a naphtha product having a desired level of sulfur. In an aspect, the desired level of sulfur can be at least about 1 wppm to about 50 wppm, or about 1 wppm to about 30 wppm, or about 1 wppm to about 20 wppm, or about 1 wppm to about 10 wppm, or about 5 wppm to about 50 wppm, or about 5 wppm to about 30 wppm, or about 5 wppm to about 20 wppm, or about 5 wppm to about 10 wppm, or about 10 wppm to about 50 wppm, or about 10 wppm to about 30 wppm, or about 10 wppm to about 20 wppm. In other aspects, the desired level of sulfur can be about 10 wppm or less, or about 5 wppm or less.

**[0042]** In various aspects, one or more diesel and/or distillate boiling range portions of an FCC effluent can be hydrotreated. Catalysts used for hydrotreatment of a diesel boiling range or distillate boiling range portion can include conventional hydroprocessing catalysts, such as those that comprise at least one Group VIII non-noble metal (Columns 8 – 10 of IUPAC periodic table), preferably Fe, Co, and/or Ni, such as Co and/or Ni; and at least one Group VI metal (Column 6 of IUPAC periodic table), preferably Mo and/or W. Such hydroprocessing catalysts can optionally include transition metal sulfides. These metals or mixtures of metals are typically present as oxides or sulfides on refractory metal oxide supports. Suitable metal oxide supports include low acidic oxides such as silica, alumina, titania, silica-titania, and titania-alumina. Suitable aluminas are porous aluminas such as gamma or eta having average pore sizes from 50 to 200 Å, or 75 to 150 Å; a surface area from 100 to 300 m<sup>2</sup>/g, or 150 to 250 m<sup>2</sup>/g; and a pore volume of from 0.25 to 1.0 cm<sup>3</sup>/g, or 0.35 to 0.8 cm<sup>3</sup>/g. The supports are preferably not promoted with a halogen such as fluorine as this generally increases the acidity of the support.

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**[0043]** The at least one Group VIII non-noble metal, in oxide form, can typically be present in an amount ranging from about 2 wt% to about 40 wt%, preferably from about 4 wt% to about 15 wt%. The at least one Group VI metal, in oxide form, can typically be present in an amount ranging from about 2 wt% to about 70 wt%, preferably for supported catalysts from about 6 wt% to about 40 wt% or from about 10 wt% to about 30 wt%. These weight percents are based on the total weight of the catalyst. Suitable metal catalysts include cobalt/molybdenum (1-10% Co as oxide, 10-40% Mo as oxide), nickel/molybdenum (1-10% Ni as oxide, 10-40% Co as oxide), or nickel/tungsten (1-10% Ni as oxide, 10-40% W as oxide) on alumina, silica, silica-alumina, or titania.

**[0044]** Alternatively, the hydrotreating catalyst for a diesel boiling range or distillate boiling range portion of an FCC effluent can be a bulk metal catalyst, or a combination of stacked beds of supported and bulk metal catalyst. By bulk metal, it is meant that the catalysts are unsupported wherein the bulk catalyst particles comprise 30-100 wt. % of at least one Group VIII non-noble metal and at least one Group VIB metal, based on the total weight of the bulk catalyst particles, calculated as metal oxides and wherein the bulk catalyst particles have a surface area of at least 10 m<sup>2</sup>/g. It is furthermore preferred that the bulk metal hydrotreating catalysts used herein comprise about 50 to about 100 wt%, and even more preferably about 70 to about 100 wt%, of at least one Group VIII non-noble metal and at least one Group VIB metal, based on the total weight of the particles, calculated as metal oxides. The amount of Group VIB and Group VIII non-noble metals can easily be determined VIB TEM-EDX.

**[0045]** Bulk catalyst compositions comprising one Group VIII non-noble metal and two Group VIB metals are preferred. It has been found that in this case, the bulk catalyst particles are sintering-resistant. Thus the active surface area of the bulk catalyst particles is maintained during use. The molar ratio of Group VIB to Group VIII non-noble metals ranges generally from 10:1-1:10 and preferably from 3:1-1:3. In the case of a core-shell structured particle, these ratios of course apply to the metals contained in the shell. If more than one Group VIB metal is contained in the bulk catalyst particles, the ratio of the different Group VIB metals is generally not critical. The same holds when more than one Group VIII non-noble metal is applied. In the case where molybdenum and tungsten are present as Group VIB metals, the molybdenum:tungsten ratio preferably lies in the range of 9:1-1:9. Preferably the Group VIII non-noble metal comprises nickel and/or cobalt. It is further preferred that the Group VIB metal comprises a combination of molybdenum and tungsten. Preferably, combinations of nickel/molybdenum/tungsten and cobalt/molybdenum/tungsten and nickel/cobalt/molybdenum/tungsten are used. These types of precipitates appear to be sinter-resistant. Thus, the active surface area of the precipitate is

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maintained during use. The metals are preferably present as oxidic compounds of the corresponding metals, or if the catalyst composition has been sulfided, sulfidic compounds of the corresponding metals.

**[0046]** It is also preferred that the bulk metal hydrotreating catalysts used herein have a surface area of at least 50 m<sup>2</sup>/g and more preferably of at least 100 m<sup>2</sup>/g. It is also desired that the pore size distribution of the bulk metal hydrotreating catalysts be approximately the same as the one of conventional hydrotreating catalysts. Bulk metal hydrotreating catalysts have a pore volume of 0.05-5 ml/g, or of 0.1-4 ml/g, or of 0.1-3 ml/g, or of 0.1-2 ml/g determined by nitrogen adsorption. Preferably, pores smaller than 1 nm are not present. The bulk metal hydrotreating catalysts can have a median diameter of at least 50 nm, or at least 100 nm. The bulk metal hydrotreating catalysts can have a median diameter of not more than 5000 μm, or not more than 3000 μm. In an embodiment, the median particle diameter lies in the range of 0.1-50 μm and most preferably in the range of 0.5-50 μm.

**[0047]** The hydrotreatment of a diesel boiling range portion or distillate boiling range portion can be carried out in the presence of hydrogen. A hydrogen stream is, therefore, fed or injected into a vessel or reaction zone or hydroprocessing zone in which the hydroprocessing catalyst is located. Hydrogen, which is contained in a hydrogen-containing "treat gas," is provided to the reaction zone. Treat gas, as referred to in this invention, can be either pure hydrogen or a hydrogen-containing gas, which is a gas stream containing hydrogen in an amount that is sufficient for the intended reaction(s), optionally including one or more other gasses (e.g., nitrogen and light hydrocarbons such as methane), and which will not adversely interfere with or affect either the reactions or the products. Impurities, such as H<sub>2</sub>S and NH<sub>3</sub> are undesirable and would typically be removed from the treat gas before it is conducted to the reactor. The treat gas stream introduced into a reaction stage will preferably contain at least about 50 vol. % and more preferably at least about 75 vol. % hydrogen.

**[0048]** Hydrotreating conditions for a diesel boiling range portion and/or distillate boiling range portion can include temperatures of about 200°C to about 450°C, or about 315°C to about 425°C; pressures of about 250 psig (1.8 MPag) to about 5000 psig (34.6 MPag) or about 300 psig (2.1 MPag) to about 3000 psig (20.8 MPag); liquid hourly space velocities (LHSV) of about 0.1 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>; and hydrogen treat rates of about 200 scf/B (35.6 m<sup>3</sup>/m<sup>3</sup>) to about 10,000 scf/B (1781 m<sup>3</sup>/m<sup>3</sup>), or about 500 (89 m<sup>3</sup>/m<sup>3</sup>) to about 10,000 scf/B (1781 m<sup>3</sup>/m<sup>3</sup>).

#### Product Properties – Hydrotreated Effluent and FCC Products

**[0049]** The FCC effluent and/or hydrotreated FCC effluent from processing the atmospheric resid boiling range portion of a tight oil can be characterized in various manners.



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**[0050]** In some aspects, the FCC effluent can include at least about 10 wt% of 1050°F+ (566°C) compounds, or at least about 15 wt%. Additionally or alternately, the FCC effluent can include about 1 wppm to about 3 wppm of metals, such as about 1 wppm to about 3 wppm of Ni, Cr, and/or V. Additionally or alternately, can include about 1 wt% to about 5 wt% of Conradson Carbon Residue (CCR).

**[0051]** In some aspects, the FCC effluent can include one or more naphtha boiling range fractions, one or more diesel boiling range fractions, and a catalytic slurry oil or bottoms fraction. Optionally, a combined yield of the one or more naphtha boiling range fractions from the FCC effluent and the naphtha boiling range fraction(s) separated from the tight oil fraction can correspond to 20 wt% to 50 wt% of the tight oil fraction. Optionally, a combined yield of the one or more diesel boiling range fractions from the FCC effluent and the diesel boiling range fraction(s) separated from the tight oil fraction can correspond to 20 wt% to 50 wt% of the tight oil fraction. Optionally, a combined yield of the various fuel boiling range fractions (naphtha boiling range fractions and diesel boiling range fractions from the FCC effluent and separated from the tight oil fraction) can correspond to at least 60 wt% of the tight oil fraction, or at least 70 wt%, or at least 80 wt%.

**[0052]** In various aspects, the FCC effluent derived from a tight oil feed can also provide a combination of unexpected properties. The unexpected combination of properties can include properties related to the fuel value of underlying fractions, the olefin content of underlying fractions, and/or the quality of the bottoms fraction (i.e., main column bottoms) generated during FCC processing.

**[0053]** FIG. 2 provides a comparison of selected properties (as generated by an empirical compositional model) of FCC effluents from a conventional feed and a tight oil feed. The conventional feed corresponds to a synthetic crude derived from a tar sands formation. The FCC effluent was fractionated to form at least a light catalytic naphtha fraction, a heavy catalytic naphtha fraction, and a light cycle oil having the boiling ranges shown in FIG. 2. The remaining heavier portion of the effluent corresponded to the main column bottoms.

**[0054]** In the modeled results shown in FIG. 2, the light catalytic naphtha and heavy catalytic naphtha from the tight oil feed have similar octane numbers but higher olefin contents relative to the fractions derived from the conventional feed. Additionally, the cetane number of the light cycle oil from the tight oil feed is higher than the corresponding fraction from the conventional feed. Also, the API gravity of the main column bottoms is lower for the tight oil feed, which can be beneficial for identifying processing options for making further use of the bottoms fraction. This combination of higher olefin contents in fuel fractions, improved cetane for the light cycle oil while

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maintaining similar octane for the naphtha fractions, and/or a higher API gravity bottoms is unexpected.

**[0055]** More generally, the FCC effluent derived from a tight oil feed can have one or more of the following properties: **1)** a light catalytic naphtha fraction (T5 – T95 boiling range of 28°C to 165°C) having a research octane number of at least 90, or at least 93, a motor octane number of at least 80, or at least 81, and/or an olefin content of at least 35 wt%, or at least 40 wt%; **2)** a heavy catalytic naphtha fraction (T5 – T95 boiling range of 150°C to 255°C) having a research octane number of at least 90, or at least 92, a motor octane number of at least 78, or at least 79, and/or an olefin content of at least 6 wt%, or at least 8 wt%, or at least 9 wt%; **3)** a light cycle oil (T5 – T95 boiling range of 225°C to 400°C) having a cetane index of at least 20.0; and **4)** a main column bottoms having an API gravity of at least -10 or at least -9.

#### Configuration Example – FCC Processing of Tight Oil Atmospheric Resid

**[0056]** FIG. 1 shows an example of a configuration for processing a tight oil fraction (possibly corresponding to a whole tight oil crude) using fluid catalytic cracking and without exposing the tight oil fraction to a fractionation process having a pressure of less than about 15 kPa. In the configuration shown in FIG. 1, a tight oil fraction 105 is passed into an atmospheric distillation unit 120. The tight oil fraction 105 is separated in atmospheric distillation unit 120 to form a light ends (C<sub>4</sub>-) fraction 121, one or more naphtha boiling range fractions 122, one or more distillate boiling range fractions 126, and a bottoms fraction 125. The bottoms fraction 125 can have a T5 boiling point of at least about 650°F (343°C), or at least about 700°F (371°C). Optionally, if prior separations have been performed on tight oil fraction 105, the tight oil fraction may not include lower boiling range material. In this situation, the light ends fraction 121 and/or the one or more naphtha boiling range fractions 122 may not be formed. As an alternative to using an atmospheric distillation unit 120, a flash fractionator or another type of separator may be used. In such aspects, a single lower boiling fraction may be formed along with bottoms fraction 125, as opposed to the configuration in FIG. 1 where distinct distillate boiling range fraction(s) 126 and naphtha boiling range fraction(s) 122 are formed.

**[0057]** After separation, the one or more naphtha boiling range fractions 122 and/or the one or more distillate boiling range fractions 126 can optionally be hydrotreated. The bottoms fraction 125 can be passed into a fluid catalytic cracking unit 140 for fluid catalytic cracking of the bottoms fraction 125. Optionally, a co-feed 135 having a metals content of about 1 – 3 wppm of metals can also be introduced into fluid catalytic cracking unit 140. Examples of a suitable co-feed 135 can include, but are not limited to, distillate boiling range feeds, vacuum gas oil boiling range feeds, heavy coker gas oils, and other feeds having a sufficiently low metals content. The effluent

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from the fluid catalytic cracking unit 140 can correspond to a variety of fractions. In the configuration shown in FIG. 1, the various fractions can include a light ends fraction 141, a light catalytic naphtha 142, a heavy catalytic naphtha 144, a light cycle oil 146, a heavy cycle oil 148, and a bottoms or catalytic slurry oil fraction 149. In other configurations, fewer types of fractions may be formed from the fluid catalytic cracking effluent. For example, a heavy cycle oil may not be formed, so that the effluent includes a light cycle oil fraction and a catalytic slurry oil fraction. One or more of these fractions can emerge from the fluid catalytic cracking unit 140 as a single effluent that is subsequently separated (not shown) using a distillation column or another suitable separator. The light catalytic naphtha 142, the heavy catalytic naphtha 144, the light cycle oil 146, and/or the heavy cycle oil 148 can optionally be hydrotreated to reduce the sulfur content of the fraction(s).

#### Additional Embodiments

**[0058]** Embodiment 1. A method for processing a tight oil fraction: separating a tight oil fraction at a pressure of at least 5 psig (35 kPa) to form at least a higher boiling fraction having a T5 boiling point of at least about 650°F (343°C) and a second fraction having a lower T5 boiling point than the higher boiling fraction, the higher boiling fraction comprising about 5 wppm to about 10 wppm of metals and at least about 20 wt% of 1050°F+ compounds, or at least about 30 wt%, or at least about 40 wt%; and exposing the higher boiling fraction to a cracking catalyst under effective fluid catalytic cracking conditions to form a cracked effluent comprising at least about 5 wt% of 1050°F+ compounds, or at least about 10 wt%.

**[0059]** Embodiment 2. The method of Embodiment 1, further comprising separating the cracked effluent to form a first naphtha boiling range fraction, a first diesel boiling range fraction, and a catalytic slurry oil fraction, the catalytic slurry oil fraction comprising the at least about 10 wt% of 1050°F+ compounds of the cracked effluent.

**[0060]** Embodiment 3. The method of Embodiment 2, wherein the second fraction comprises at least a second naphtha boiling range portion and a second diesel boiling range portion, a combined yield of the first naphtha boiling range portion, the second naphtha boiling range portion, the first diesel boiling range portion, and the second diesel boiling range portion being at least about 60 wt% of the tight oil fraction, or at least about 70 wt%, or at least about 80 wt%.

**[0061]** Embodiment 4. The method of Embodiment 2 or 3, further comprising hydrotreating at least a portion of the cracked naphtha boiling range fraction, at least a portion of the diesel boiling range fraction, or a combination thereof.

**[0062]** Embodiment 5. The method of any of the above embodiments, wherein the higher boiling fraction comprises at least about 25 wt% of 1050°F+ compounds, or at least about 30 wt%.

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[0063] Embodiment 6. The method of any of the above embodiments, wherein the higher boiling fraction comprises about 5 wppm to about 10 wppm of Ni, Cr, and V, or wherein the higher boiling fraction comprises about 5 wppm to about 7 wppm of metals, or a combination thereof.

[0064] Embodiment 7. The method of any of the above embodiments, wherein the higher boiling fraction comprises about 3 wt% to about 10 wt% of Conradson Carbon Residue, the cracked effluent comprising about 1 wt% to about 5 wt% of Conradson Carbon Residue.

[0065] Embodiment 8. The method of any of the above embodiments, wherein the higher boiling fraction is exposed to the cracking catalyst without being exposed to a pressure of less than 15 kPag.

[0066] Embodiment 9. The method of any of the above embodiments, wherein exposing the higher boiling fraction to a cracking catalyst comprises exposing the higher boiling fraction and a co-feed to the cracking catalyst, the co-feed having a T95 boiling point of about 1050°F or less and a metal content of about 1 – 3 wppm.

[0067] Embodiment 10. The method of any of the above embodiments, wherein the higher boiling fraction comprises an atmospheric resid fraction.

[0068] Embodiment 11. The method of any of the above embodiments, wherein the higher boiling fraction comprises about 500 wppm to about 20,000 wppm sulfur, or about 500 wppm to about 5000 wppm sulfur.

[0069] Embodiment 12. The method of any of the above embodiments, wherein the tight oil fraction is derived from a crude oil extracted from a formation having a production rate of less than 100 barrels per day in the absence of hydraulic fracturing, or less than 10 barrels per day in the absence of hydraulic fracturing.

[0070] Embodiment 13. A fluid catalytic cracking effluent formed according to the method of any of the above embodiments.

[0071] Embodiment 14. A fluid catalytic cracking effluent comprising a light catalytic naphtha fraction, a heavy catalytic naphtha fraction, a light cycle oil, and a main column bottoms, the light catalytic naphtha fraction having a research octane number of at least 90 (or at least 93) and an olefin content of at least 35 wt% (or at least 40 wt%), the heavy catalytic naphtha having a research octane number of at least 90 (or at least 92) and optionally an olefin content of at least 6 wt% (or at least 8 wt% or at least 9 wt%), the light cycle oil having a cetane index of at least 20.0, and the main column bottoms optionally having an API gravity of at least -10, or at least -9.

[0072] Embodiment 15. The fluid catalytic cracking effluent of claim 15, wherein the light catalytic naphtha fraction has a motor octane number of at least 80, or at least 81, or wherein the

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heavy catalytic naphtha fraction has a motor octane number of at least 78, or at least 79, or a combination thereof.

**[0073]** When numerical lower limits and numerical upper limits are listed herein, ranges from any lower limit to any upper limit are contemplated. While the illustrative embodiments of the invention have been described with particularity, it will be understood that various other modifications will be apparent to and can be readily made by those skilled in the art without departing from the spirit and scope of the invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the examples and descriptions set forth herein but rather that the claims be construed as encompassing all the features of patentable novelty which reside in the present invention, including all features which would be treated as equivalents thereof by those skilled in the art to which the invention pertains.

**[0074]** The present invention has been described above with reference to numerous embodiments and specific examples. Many variations will suggest themselves to those skilled in this art in light of the above detailed description. All such obvious variations are within the full intended scope of the appended claims.

**CLAIMS:**

1. A method for processing a tight oil fraction:  
separating a tight oil fraction at a pressure of at least 5 psig (35 kPa) to form at least a higher boiling fraction having a T5 boiling point of at least about 650°F (343°C) and a second fraction having a lower T5 boiling point than the higher boiling fraction, the higher boiling fraction comprising about 5 wppm to about 10 wppm of metals and at least about 20 wt% of 1050°F+ compounds; and  
exposing the higher boiling fraction to a cracking catalyst under effective fluid catalytic cracking conditions to form a cracked effluent comprising at least about 5 wt% of 1050°F+ compounds.
2. The method of claim 1, further comprising separating the cracked effluent to form a first naphtha boiling range fraction, a first diesel boiling range fraction, and a catalytic slurry oil fraction, the catalytic slurry oil fraction comprising the at least about 10 wt% of 1050°F+ compounds of the cracked effluent.
3. The method of claim 2, wherein the second fraction comprises at least a second naphtha boiling range portion and a second diesel boiling range portion, a combined yield of the first naphtha boiling range portion, the second naphtha boiling range portion, the first diesel boiling range portion, and the second diesel boiling range portion being at least about 70 wt% of the tight oil fraction.
4. The method of claim 2, further comprising hydrotreating at least a portion of the cracked naphtha boiling range fraction, at least a portion of the diesel boiling range fraction, or a combination thereof.
5. The method of claim 1, wherein the higher boiling fraction comprises at least about 25 wt% of 1050°F+ compounds.
6. The method of claim 1, wherein the higher boiling fraction comprises about 5 wppm to about 10 wppm of Ni, Cr, and V.
7. The method of claim 1, wherein the higher boiling fraction comprises about 5 wppm to about 7 wppm of metals.
8. The method of claim 1, wherein the higher boiling fraction comprises about 3 wt% to about 10 wt% of Conradson Carbon Residue, the cracked effluent comprising about 1 wt% to about 5 wt% of Conradson Carbon Residue.
9. The method of claim 1, wherein the higher boiling fraction is exposed to the cracking catalyst without being exposed to a pressure of less than 15 kPag.

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10. The method of claim 1, wherein exposing the higher boiling fraction to a cracking catalyst comprises exposing the higher boiling fraction and a co-feed to the cracking catalyst, the co-feed having a T95 boiling point of about 1050°F or less and a metal content of about 1 – 3 wppm.

11. The method of claim 1, wherein the higher boiling fraction comprises an atmospheric resid fraction.

12. The method of claim 1, wherein the higher boiling fraction comprises about 500 wppm to about 5000 wppm sulfur.

13. The method of claim 1, wherein the tight oil fraction is derived from a crude oil extracted from a formation having a production rate of less than 100 barrels per day in the absence of hydraulic fracturing.

14. The method of claim 1, wherein the tight oil fraction is derived from a crude oil extracted from a formation having a production rate of less than 10 barrels per day in the absence of hydraulic fracturing.

15. A fluid catalytic cracking effluent comprising a light catalytic naphtha fraction, a heavy catalytic naphtha fraction, a light cycle oil, and a main column bottoms, the light catalytic naphtha fraction having a research octane number of at least 90 and an olefin content of at least 35 wt%, the heavy catalytic naphtha having a research octane number of at least 90, and the light cycle oil having a cetane index of at least 20.0.

16. The fluid catalytic cracking effluent of claim 15, wherein the main column bottoms having an API gravity of at least -9.

17. The fluid catalytic cracking effluent of claim 15, wherein the light catalytic naphtha fraction has a research octane number of at least 93, an olefin content of at least 40 wt%, or a combination thereof.

18. The fluid catalytic cracking effluent of claim 15, wherein the heavy catalytic naphtha fraction has an olefin content of at least 6 wt%.

19. The fluid catalytic cracking effluent of claim 15, wherein the heavy catalytic naphtha fraction has a research octane number of at least 92, an olefin content of at least 8 wt%, or a combination thereof.

20. The fluid catalytic cracking effluent of claim 15, wherein the light catalytic naphtha fraction has a motor octane number of at least 80, or wherein the heavy catalytic naphtha fraction has a motor octane number of at least 78, or a combination thereof.

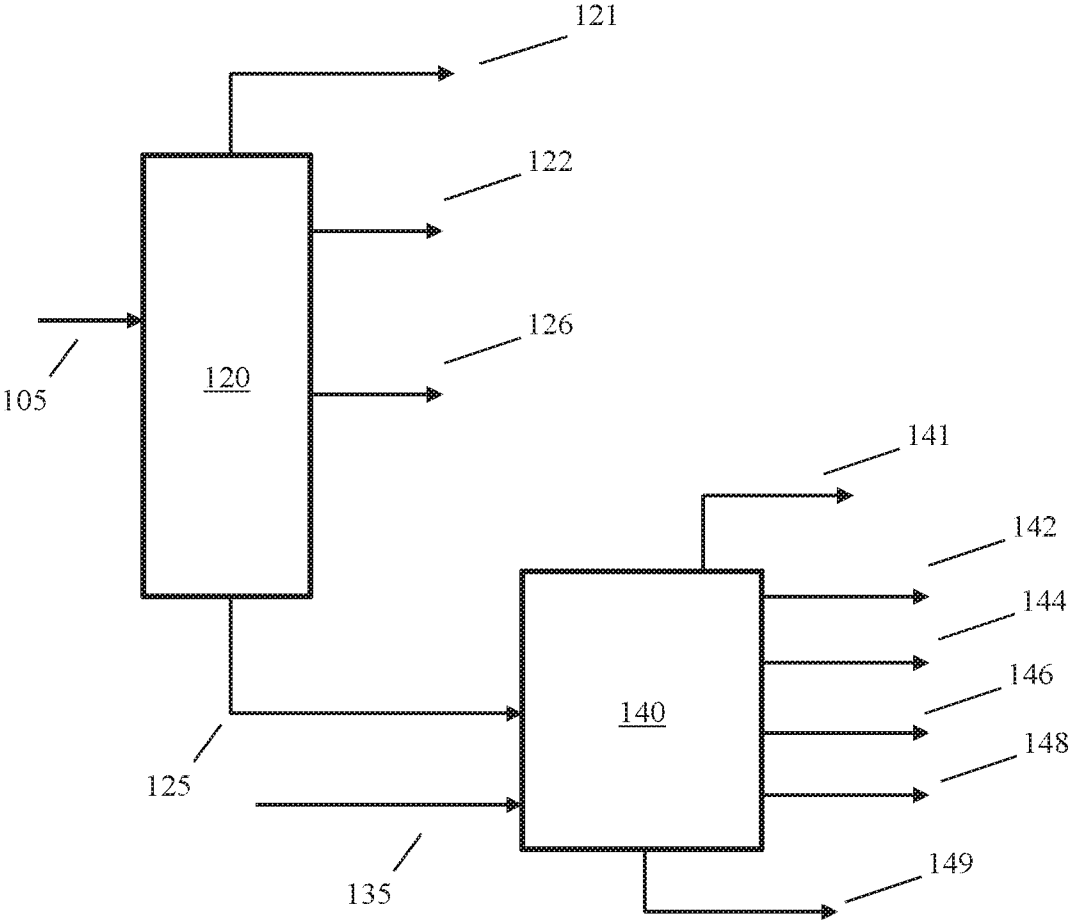


FIG. 1



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FCC effluent properties	Synthetic Crude Derived Feed	Tight oil Derived Feed
<b>Light Cat Naphtha</b>		
T5 – T95 boiling range (°C)	28 – 165	28 - 165
RON / MON	93.0 / 81.0	93.5 / 81.1
Paraffins / Olefins / Naphthenes / Aromatics (wt%)	27.7 / 32.2 / 16.5 / 23.6	25.1 / 40.0 / 13.9 / 21.1
<b>Heavy Cat Naphtha</b>		
T5 – T95 boiling range (°C)	151 - 252	152 – 252
RON / MON	92.8 / 79.4	92.5 / 78.5
Paraffins / Olefins / Naphthenes / Aromatics (wt%)	9.1 / 5.6 / 18.1 / 67.3	9.6 / 9.3 / 16.1 / 65.0
<b>Light Cycle Oil</b>		
T5 – T95 boiling range (°C)	225 - 396	227 – 398
Cetane Index	19.2	20.6
Paraffins / Olefins / Naphthenes / Aromatics (wt%)	3.0 / 0.8 / 4.9 / 91.2	3.4 / 1.5 / 5.6 / 89.5
<b>Main Column Bottoms</b>		
T5 – T95 boiling range (°C)	352 - 495	355 – 505
API Gravity	-10.9	-8.8

FIG. 2

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US2016/064525

## Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.: 15-20  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:  
see FURTHER INFORMATION sheet PCT/ISA/210
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

### Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

## INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2016/064525

A. CLASSIFICATION OF SUBJECT MATTER  
INV. C10G11/18  
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
C10G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Kenneth Bryden ET AL: "Processing Tight Oils in FCC: Issues, Opportunities and Flexible Catalytic Solutions", Grace Catalysts Technologies Catalagram. Issue No. 114 / 2014, 29 March 2014 (2014-03-29), XP055343778, Retrieved from the Internet: URL:https://grace.com/catalysts-and-fuels/en-us/Documents/114-Processing%20Tight%20Oils%20in%20FCC.pdf [retrieved on 2017-02-08] pages 4-7	1-14
X	GB 2 073 238 A (ASHLAND OIL INC) 14 October 1981 (1981-10-14) claims 1-19 figure 1 ----- -/-	1-14



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

10 February 2017

Date of mailing of the international search report

21/02/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040,  
Fax: (+31-70) 340-3016

Authorized officer

Pardo Torre, J

## INTERNATIONAL SEARCH REPORT

International application No

PCT/US2016/064525

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>Mary Jo Wier ET AL: "Optimizing Naphtha Complexes in the Tight Oil Boom", UOP LLC, a Honeywell Company, 25 March 2014 (2014-03-25), XP055343807, American Fuel &amp; Petrochemical Manufacturers Retrieved from the Internet: URL:<a href="https://www2.afpm.org/forms/uploadFiles/9E5A700000A6F.toc.AM-14-35_-_Wier_-_Optimizing_Naphtha-JLH-kl.pdf">https://www2.afpm.org/forms/uploadFiles/9E5A700000A6F.toc.AM-14-35_-_Wier_-_Optimizing_Naphtha-JLH-kl.pdf</a> [retrieved on 2017-02-08] pages 12-14</p> <p>-----</p>	1-14
A	<p>Alexis Shackelford: "Capturing maximum value with tight oil feeds in the FCC", BASF Catalysts, 1 January 2014 (2014-01-01), XP055343791, Digital Refining Retrieved from the Internet: URL:<a href="http://www.digitalrefining.com/article/1000925,Capturing_maximum_value_with_tight_oil_feeds_in_the_FCC.html#.WJtC6HrdfSg">http://www.digitalrefining.com/article/1000925,Capturing_maximum_value_with_tight_oil_feeds_in_the_FCC.html#.WJtC6HrdfSg</a> [retrieved on 2017-02-08] the whole document</p> <p>-----</p>	1-14
A	<p>A. Shackelford ET AL: "Improve refining of tight oil via enhanced fluid catalytic cracking catalysts", BASF, 1 September 2014 (2014-09-01), XP055343782, Hydrocarbon Processing Retrieved from the Internet: URL:<a href="http://www.hydrocarbonprocessing.com/magazine/2014/september-2014/special-report-refining-developments/improve-refining-of-tight-oil-via-enhanced-fluid-catalytic-cracking-catalysts">http://www.hydrocarbonprocessing.com/magazine/2014/september-2014/special-report-refining-developments/improve-refining-of-tight-oil-via-enhanced-fluid-catalytic-cracking-catalysts</a> [retrieved on 2017-02-08] the whole document</p> <p>-----</p>	1-14

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/064525

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB 2073238	A	14-10-1981	AU 6914981 A 15-10-1981
			BR 8102078 A 13-10-1981
			CA 1180296 A 01-01-1985
			GB 2073238 A 14-10-1981
			IL 62593 A 28-02-1985
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**FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210**

Continuation of Box II.2

Claims Nos.: 15-20

1 A meaningful search is not possible on the basis of claims 15-20.

1.1 Claim 15 defines an FCC effluent comprising a light catalytic naphtha, a heavy catalytic naphtha, a light cycle oil and a bottom stream. The claim then defines the properties of each of the lighter streams. This makes the claim unclear because a single product is claimed, namely the FCC effluent, but the properties are given only for portions or cuts of said single stream.

1.2 Moreover, it is not even clear how each portion or cut contributes to the total, e.g. weight percentage and/or exact boiling range (separate and distinct from the boiling range of the other cuts). Also, the boiling ranges T5-T95 disclosed in paragraph 55 of the description overlap between different cuts, and do not provide an exhaustive composition of the FCC effluent.

1.3 As consequence, it is unclear how the different fractions of claim 15 are defined and how their properties are measured, e.g. octane number, olefin content.

1.4 Claim 15 and dependent claims 16 to 20 are thus unclear to such extent that no meaningful search can be performed.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guidelines C-IV, 7.2), should the problems which led to the Article 17(2) declaration be overcome.