

CYCLE OIL CONVERSION PROCESS

FIELD OF THE INVENTION

5 **[0001]** The present invention relates to a process for converting cycle oils produced in catalytic cracking reactions into olefins and naphtha. More particularly, the invention relates to a process for converting a catalytically cracked cycle oil such as heavy cycle oil ("HCO" or "HCCO"), light cycle oil ("LCO" or "LCCO"), and mixtures thereof into olefins and naphthas using a
10 zeolite catalyst.

BACKGROUND OF THE INVENTION

[0002] Cycle oils such as LCCO produced in fluidized catalytic cracking ("FCC") reactions contain two-ring aromatic species such as naphthalene. The need for blendstocks for forming low emissions fuels has created an increased
15 demand for FCC products that contain a diminished concentration of multi-ring aromatics. There is also an increased demand for FCC products containing light olefins that may be separated for use in alkylation, oligomerization, polymerization, and MTBE and ETBE synthesis processes. There is a particular need for low emissions, high octane FCC products having an increased
20 concentration of C₂ to C₄ olefins and a reduced concentration of multi-ring aromatics and olefins of higher molecular weight.

[0003] A high octane gasoline may be formed conventionally by hydrotreating an FCC cycle oil and then re-cracking hydrotreated cycle oil. The hydrotreated cycle oil may be recycled to the FCC unit from which it was
25 derived, or it may be re-cracked in an additional catalytic cracking unit.

[0004] In such conventional processes, hydrotreating a cycle oil such as LCCO results in partial saturation of bicyclic hydrocarbon species such as

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naphthalene to produce tetrahydronaphthalene and alkyl-substituted derivatives thereof, collectively referred to herein as tetralins. The hydrotreating is performed under conditions that result in partially saturating the cycle oil's aromatic species. For example, in one conventional process a cycle oil
5 containing naphthalene as the most abundant aromatic species is hydrotreated under relatively mild conditions so that tetralins are the most abundant aromatic species in the hydrotreated product.

[0005] Unfortunately, re-cracking the hydrotreated cycle oil in accordance with the conventional processes results in undesirable hydrogen transfer
10 reactions that convert partially saturated species such as tetralins into polynuclear aromatics such as naphthalene.

[0006] There remains a need, therefore, for new processes for forming naphtha and olefin from hydrotreated cycle oils such as LCCO.

SUMMARY OF THE INVENTION

15 [0007] In one embodiment, the invention is a method for catalytically cracking a primary feed comprising:

(a) injecting the primary feed into an FCC riser reactor having at least a first reaction zone and a second reaction zone upstream of the first reaction zone, the primary feed being injected into the first reaction zone;

20 (b) cracking the primary feed in the first reaction zone under catalytic cracking conditions in the presence of a catalytically effective amount of a zeolite-containing catalytic cracking catalyst in order to form at least spent catalyst and a cracked product;

(c) separating at least a cycle oil from the cracked product and then
25 processing the cycle oil in the presence of a catalytically effective amount of a

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hydroprocessing catalyst under hydroprocessing conditions in order to form a hydroprocessed cycle oil containing a significant amount of decalins;

(d) injecting the hydroprocessed cycle oil into the second reaction zone; and

5 (e) cracking the hydroprocessed cycle oil under cycle oil catalytic cracking conditions in the presence of the catalytic cracking catalyst.

DETAILED DESCRIPTION OF THE INVENTION

[0008] The invention is based on the discovery that recycling a hydroprocessed cycle oil containing a significant amount of
10 decahydronaphthalene and alkyl-functionalized derivatives thereof (also referred to herein a "decalins) to an FCC reaction zone along the feed riser at a point upstream of gas oil or residual oil feed injection results in beneficial conversion of the hydroprocessed cycle oil into naphtha and light olefins (i.e. C₂ to C₅ olefins) such as propylene. It is believed that injecting such a hydroprocessed
15 cycle oil into the FCC reaction zone at a point upstream of gas oil or residual oil injection suppresses undesirable hydrogen transfer reactions by re-cracking potential hydrogen donors present in the cycle oil before such donors can contact the primary feed.

[0009] Preferred hydrocarbonaceous feeds (i.e. the primary feed) for the
20 catalytic cracking process described herein include naphtha, hydrocarbonaceous oils boiling in the range of about 430°F to about 1050°F, such as gas oil; heavy hydrocarbonaceous oils comprising materials boiling above 1050°F; heavy and reduced petroleum crude oil; petroleum atmospheric distillation bottoms; petroleum vacuum distillation bottoms; pitch, asphalt, bitumen, other heavy
25 hydrocarbon residues; tar sand oils; shale oil; liquid products derived from coal liquefaction processes, and mixtures thereof.

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[0010] The preferred cracking process may be performed in one or more conventional FCC process units. Each unit comprises a riser reactor having a first reaction zone and a second reaction zone upstream of the first reaction zone, a stripping zone, a catalyst regeneration zone, and at least one separation zone.

5 [0011] The primary feed is conducted to the riser reactor where it is injected into the first reaction zone wherein the primary feed contacts a flowing source of hot, regenerated catalyst. The hot catalyst vaporizes and cracks the feed at a temperature from about 450°C to 650°C, preferably from about 500°C to 600°C. The cracking reaction deposits carbonaceous hydrocarbons, or coke,
10 on the catalyst, thereby deactivating the catalyst. The cracked products may be separated from the coked catalyst and a portion of the cracked products may be conducted to a separator such as a fractionator. At least a cycle oil fraction, preferably an LCCO fraction, is separated from the cracked products in the separation zone. Other fractions that may be separated from the cracked products
15 include light olefin fractions and naphtha fractions.

[0012] Light olefins separated from the process may be used as feeds for processes such as oligimerization, polymerization, co-polymerization, ter-polymerization, and related processes (hereinafter "polymerization") in order to form macromolecules. Such light olefins may be polymerized both alone and in
20 combination with other species, in accordance with polymerization methods known in the art. In some cases it may be desirable to separate, concentrate, purify, upgrade, or otherwise process the light olefins prior to polymerization. Propylene and ethylene are preferred polymerization feeds. Polypropylene and polyethylene are preferred polymerization products made therefrom.

25 [0013] The coked catalyst flows through the stripping zone where volatiles are stripped from the catalyst particles with a stripping material such as steam. The stripping may be performed under low severity conditions in order

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to retain adsorbed hydrocarbons for heat balance. The stripped catalyst is then conducted to the regeneration zone where it is regenerated by burning coke on the catalyst in the presence of an oxygen-containing gas, preferably air.

Decoking restores catalyst activity and simultaneously heats the catalyst to, e.g.,
5 650°C to 800°C. The hot catalyst is then recycled to the riser reactor at a point near or just upstream of the second reaction zone. Flue gas formed by burning coke in the regenerator may be treated for removal of particulates and for conversion of carbon monoxide, after which the flue gas is normally discharged into the atmosphere.

10 **[0014]** As discussed, a cycle oil product is separated from the cracked products. Subsequently, at least a portion of the cycle oil is hydroprocessed in the presence of a hydroprocessing catalyst under hydroprocessing conditions in order to form a hydroprocessed cycle oil having a substantial concentration of decalins such as decahydronaphthalene and alkyl-substituted derivatives thereof.
15 At least a portion of the hydroprocessed cycle oil is conducted to the riser reactor and injected into the second reaction zone. The hydroprocessing may occur in one or more hydroprocessing reactors.

[0015] Preferred process conditions in the riser reactor's first reaction zone include temperatures from about 450°C to about 650°C, preferably from
20 about 525°C to 600°C, hydrocarbon partial pressures from about 10 to 40 psia, preferably from about 20 to 35 psia; and a catalyst to primary feed (wt/wt) ratio from about 3 to 12, preferably from about 4 to 10, where catalyst weight is total weight of the catalyst composite. Though not required, it is also preferred that steam be concurrently introduced with the primary feed into the reaction zone,
25 with the steam comprising up to about 10 wt.%, preferably about 2 to about 3 wt.% of the primary feed. Also, it is preferred that the primary feed's residence time in the reaction zone be less than about 20 seconds, preferably from about 2 to about 20 seconds, and more preferably from about 1 to about 6 seconds.

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[0016] Preferred process conditions in the riser reactor's second reaction zone include temperatures from about 550°C to about 700°C, preferably from about 525°C to 650°C, hydrocarbon partial pressures from about 10 to 40 psia, preferably from about 20 to 35 psia; and a catalyst to cycle oil (wt/wt) ratio from about 5 to 100, preferably from about 10 to 100, where catalyst weight is total weight of the catalyst composite. Though not required, it is also preferred that steam be concurrently introduced with the cycle oil feed into the reaction zone, with the steam comprising from about 2 wt.% to about 50 wt.%, and preferably up to about 10 wt.%, based on the weight of the primary feed. Also, it is preferred that the cycle oil's residence time in the reaction zone be less than about 10 seconds; for example, from about 0.1 to 10 seconds.

[0017] A preferred, fluidized catalytic cracking catalyst ("catalyst" herein) is a composition of catalyst particles and other reactive and non-reactive components. More than one type of catalyst particle may be present in the catalyst. A preferred catalyst particle useful in the invention contains at least one crystalline aluminosilicate, also referred to as zeolite, of average pore diameter greater than about 0.7 nanometers (nm), i.e., large pore zeolite cracking catalyst. The pore diameter also sometimes referred to as effective pore diameter can be measured using standard adsorption techniques and hydrocarbons of known minimum kinetic diameters. See Breck, *Zeolite Molecular Sieves*, 1974 and Anderson et al., *J. Catalysis* 58, 114 (1979), both of which are incorporated herein by reference. Zeolites useful in the invention are described in the "Atlas of Zeolite Structure Types," eds. W. H. Meier and D. H. Olson, Butterworth-Heinemann, Third Edition, 1992, which is hereby incorporated by reference. As discussed, the catalyst may be in the form of particles containing zeolite. The catalyst may also include fines, inert particles, particles containing a metallic species, and mixtures thereof. Particles containing metallic species include platinum compounds, platinum metal, and mixtures thereof.

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[0018] Catalyst particles may contain metals such as platinum, promoter species such as phosphorous-containing species, clay filler, and species for imparting additional catalytic functionality (additional to the cracking functionality) such as bottoms cracking and metals passivation. Such an additional catalytic functionality may be provided, for example, by aluminum-containing species. More than one type of catalyst particle may be present in the catalyst. For example, individual catalyst particles may contain large pore zeolite, shape selective zeolite, and mixtures thereof.

[0019] The cracking catalyst particle may be held together with an inorganic oxide matrix component. The inorganic oxide matrix component binds the particle's components together so that the catalyst particle product is hard enough to survive interparticle and reactor wall collisions. The inorganic oxide matrix may be made according to conventional methods from an inorganic oxide sol or gel which is dried to "glue" the catalyst particle's components together. Preferably, the inorganic oxide matrix is not catalytically active and comprises oxides of silicon and aluminum. It is also preferred that separate alumina phases be incorporated into the inorganic oxide matrix. Species of aluminum oxyhydroxides- γ -alumina, boehmite, diaspore, and transitional aluminas such as α -alumina, β -alumina, γ -alumina, δ -alumina, ϵ -alumina, κ -alumina, and ρ -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.

[0020] Preferred catalyst particles in the present invention contain at least one of:

(a) amorphous solid acids, such as alumina, silica-alumina, silica-magnesia, silica-zirconia, silica-thoria, silica-beryllia, silica-titania, and the like; and

(b) zeolite catalysts containing faujasite.

[0021] Silica-alumina materials suitable for use in the present invention are amorphous materials containing about 10 to 40 wt.% alumina and to which other promoters may or may not be added.

5 [0022] Suitable zeolite in such catalyst particles include zeolites which are iso-structural to zeolite Y. These include the ion-exchanged forms such as the rare-earth hydrogen and ultra stable (USY) form. The zeolite may range in size from about 0.1 to 10 microns, preferably from about 0.3 to 3 microns. The zeolite will be mixed with a suitable porous matrix material in order to form the
10 fluid catalytic cracking catalyst. Non-limiting porous matrix materials which may be used in the practice of the present invention include alumina, silica-alumina, silica-magnesia, silica-zirconia, silica-thoria, silica-beryllia, silica-titania, as well as ternary compositions, such as silica-alumina-thoria, silica-alumina-zirconia, magnesia and silica-magnesia-zirconia. The matrix may also
15 be in the form of a cogel. The relative proportions of zeolite component and inorganic oxide gel matrix on an anhydrous basis may vary widely with the zeolite content, ranging from about 10 to 99, more usually from about 10 to 80, percent by weight of the dry composite. The matrix itself may possess catalytic properties, generally of an acidic nature.

20 [0023] The amount of zeolite component in the catalyst particle will generally range from about 1 to about 60 wt.%, preferably from about 1 to about 40 wt.%, and more preferably from about 5 to about 40 wt.%, based on the total weight of the catalyst. Generally, the catalyst particle size will range from about 10 to 300 microns in diameter, with an average particle diameter of about 60
25 microns. The surface area of the matrix material will be about $\leq 350 \text{ m}^2/\text{g}$, preferably 50 to $200 \text{ m}^2/\text{g}$, more preferably from about 50 to $100 \text{ m}^2/\text{g}$. While the surface area of the final catalysts will be dependent on such things as type

and amount of zeolite material used, it will usually be less than about 500 m²/g, preferably from about 50 to 300 m²/g, more preferably from about 50 to 250 m²/g, and most preferably from about 100 to 250 m²/g.

[0024] Another preferred catalyst contains a mixture of zeolite Y and
5 zeolite beta. The Y and beta zeolite may be on the same catalyst particle, on different particles, or some combination thereof. Such catalysts are described in U.S. Patent No. 5,314,612, incorporated by reference herein. Such catalyst particles consist of a combination of zeolite Y and zeolite beta combined in a matrix comprised of silica, silica-alumina, alumina, or any other suitable matrix
10 material for such catalyst particles. The zeolite portion of the resulting composite catalyst particle will consist of 25 to 95 wt.% zeolite Y with the balance being zeolite beta.

[0025] Yet another preferred catalyst contains a mixture of zeolite Y and a shape selective zeolite species such as ZSM-5 or a mixture of an amorphous
15 acidic material and ZSM-5. The Y zeolite (or alternatively the amorphous acidic material) and shape selective zeolite may be on the same catalyst particle, on different particles, or some combination thereof. Such catalysts are described in U.S. Patent No. 5,318,692, incorporated by reference herein. The zeolite portion of the catalyst particle will typically contain from about 5 wt.% to 95 wt.%
20 zeolite-Y (or alternatively the amorphous acidic material) and the balance of the zeolite portion being ZSM-5.

[0026] Shape selective zeolite species useful in the invention include medium pore size zeolites generally having a pore size from about 0.5 nm, to about 0.7 nm. Such zeolites include, for example, MFI, MFS, MEL, MTW,
25 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-

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38, ZSM-48, ZSM-50, silicalite, and silicalite 2. The most preferred is ZSM-5, which is described in U.S. Patent Nos. 3,702,886 and 3,770,614. ZSM-11 is described in U.S. Patent No. 3,709,979; ZSM-12 in U.S. Patent No. 3,832,449; ZSM-21 and ZSM-38 in U.S. Patent No. 3,948,758; ZSM-23 in U.S. Patent No. 4,076,842; and ZSM-35 in U.S. Patent No. 4,016,245. All of the above patents are incorporated herein by reference.

[0027] Other suitable medium pore size zeolites include the silicoaluminophosphates (SAPO), such as SAPO-4 and SAPO-11 which is described in U.S. Patent No. 4,440,871; chromosilicates; gallium silicates; iron silicates; aluminum phosphates (ALPO), such as ALPO-11 described in U.S. Patent No. 4,310,440; titanium aluminosilicates (TASO), such as TASO-45 described in EP-A No. 229,295; boron silicates, described in U.S. Patent No. 4,254,297; titanium aluminophosphates (TAPO), such as TAPO-11 described in U.S. Patent No. 4,500,651; and iron aluminosilicates.

[0028] The large pore and shape selective zeolites in the catalytic species can 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. Patent No. 4,229,424 which is incorporated herein by reference. The crystalline admixtures are themselves medium pore, i.e., shape selective, size zeolites and are not to be confused with physical admixtures of zeolites in which distinct crystals of crystallites of different zeolites are physically present in the same catalyst composite or hydrothermal reaction mixtures.

[0029] As set forth above, the process of the invention comprises cracking a primary feed in the first reaction zone of a riser reactor in order to form a cracked product. At least a portion of the cycle oil is separated from the cracked

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product and then hydroprocessed in order to form a hydroprocessed cycle oil having a significant decalins concentration. The hydroprocessed cycle oil is conducted to the riser reactor for injection into the second reaction zone. Such cycle oil hydroprocessing may occur in a hydroprocessing reactor under
5 hydroprocessing conditions in the presence of a hydroprocessing catalyst.

[0030] The term "hydroprocessing" is used broadly herein, and includes for example hydrogenation such as aromatics saturation, hydrotreating, hydrofining, and hydrocracking. As is known by those of skill in the art, the degree of hydroprocessing can be controlled through proper selection of catalyst as well as by optimizing
10 operation conditions. It is desirable that the hydroprocessing convert a significant amount of aromatic species such as naphthalene and tetralins to decalins using a catalytically effective amount of a hydrogenation catalyst. Objectionable species can also be removed by the hydroprocessing reactions. These species include non-hydrocarbyl species that may contain sulfur, nitrogen, oxygen, halides, and certain
15 metals.

[0031] Hydroprocessing may be performed in one or more stages consistent with the objective of maximizing conversion of multi-ring aromatics species (e.g., naphthalenes) to the corresponding fully saturated species (e.g., decahydronaphthalene). For a single-stage operation, the reaction is performed at a
20 temperature ranging from about 200°C to about 550°C, more preferably from about 250°C to about 400°C. The reaction pressure preferably ranges from about 1000 to about 3000 psig, more preferably from about 1200 to about 2500 psig, and still more preferably from about 1300 to about 2000 psig. The space velocity preferably ranges from about 0.1 to 6 V/V/Hr, more preferably from about 0.5 to about 2 V/V/Hr, and
25 still more preferably from about 0.8 to about 2 V/V/Hr, where V/V/Hr is defined as the volume of oil per hour per volume of catalyst. The hydrogen containing gas is preferably added to establish a hydrogen charge rate ranging from about 1,000 to about 15,000 standard cubic feet per barrel (SCF/B), more preferably from about 5,000 to about 10,000 SCF/B. Actual conditions employed will depend on factors such as feed
30 quality and catalyst, but should be consistent with the objective of maximizing

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conversion of multi-ring aromatic species to decahydronaphthalenes. For a two-stage operation wherein LCCO is first hydroprocessed to remove substantial amounts of sulfur and nitrogen, and convert bicyclic aromatics such as naphthalenes predominantly to partially saturated tetralins such as tetrahydronaphthalenes. The second-stage

5 hydrogenation reaction is performed at a temperature ranging from about 100°C to about 600°C, preferably from about 100°C to about 450°C, and more preferably from about 200°C to about 400°C. The reaction pressure preferably ranges from about 100 to about 3000 psig, more preferably from about 450 to about 2000 psig, and still more preferably from about 1300 psig to about 2000 psig. The space velocity preferably

10 ranges from about 0.1 to 6 V/V/Hr, preferably about 0.8 to about 2 V/V/Hr, where V/V/Hr is defined as the volume of oil per hour per volume of catalyst. The hydrogen containing gas is preferably added to establish a hydrogen charge rate ranging from about 500 to about 15,000 standard cubic feet per barrel (SCF/B), more preferably from about 500 to about 10,000 SCF/B. Actual conditions employed will depend on factors

15 such as feed quality and catalyst, but should be consistent with the objective of maximizing the concentration of decahydronaphthalenes and alkyl-substituted derivatives thereof, collectively referred to herein as decalins.

[0032] Preferably, cycle oil hydroprocessing is conducted under conditions that convert species such as naphthalene and alkyl-substituted derivatives thereof

20 ("naphthalenes") and tetrahydronaphthalene and alkyl-substituted derivatives thereof ("tetralins"). While not wishing to be bound by any theory or model, it is believed that such hydroprocessing conditions result in a hydroprocessed cycle oil that may be more readily converted to light olefins than cycle oils hydroprocessed in accordance with the conventional processes that aim to produce significant amounts of tetralins.

25 [0033] Preferably, the hydroprocessed cycle oil contains a significant amount of decalins. More preferably, decalins are the most abundant species among the cyclic and multi-cyclic species present in the hydroprocessed cycle oil. Still more preferably, the hydroprocessing is conducted so that decalins are the most abundant 2-ring species in the hydroprocessed cycle oil.

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[0034] Preferably, the total aromatics content in the hydroprocessed cycle oil is ranges from about 0 to about 5 wt.%, with a total 2-ring or larger aromatic content ranging from about 0 to about 2 wt.%. Still more preferably, the total aromatics content in the hydroprocessed cycle oil is ranges from about 0 to about 0.6 wt.%, with a total 2-
5 ring or larger aromatic content ranging from about 0 to about 0.01 wt.%.

[0035] Hydroprocessing conditions can be maintained by use of any of several types of hydroprocessing reactors. Trickle bed reactors are most commonly employed in petroleum refining applications with co-current downflow of liquid and gas phases over a fixed bed of catalyst particles. It can be advantageous to utilize alternative
10 reactor technologies. Countercurrent-flow reactors, in which the liquid phase passes down through a fixed bed of catalyst against upward-moving treat gas, can be employed to obtain higher reaction rates and to alleviate aromatics hydrogenation equilibrium limitations inherent in co-current flow trickle bed reactors. Moving bed
15 reactors can be employed to increase tolerance for metals and particulates in the hydroprocessor feed stream. Moving bed reactor types generally include reactors wherein a captive bed of catalyst particles is contacted by upward-flowing liquid and treat gas. The catalyst bed can be slightly expanded by the upward flow or
substantially expanded or fluidized by increasing flow rate, for example, via liquid recirculation (expanded bed or ebullating bed), use of smaller size catalyst particles
20 which are more easily fluidized (slurry bed), or both. In any case, catalyst can be removed from a moving bed reactor during onstream operation, enabling economic application when high levels of metals in feed would otherwise lead to short run lengths in the alternative fixed bed designs. Furthermore, expanded or slurry bed reactors with
upward-flowing liquid and gas phases would enable economic operation with
25 feedstocks containing significant levels of particulate solids, by permitting long run lengths without risk of shutdown due to fouling. Use of such a reactor would be especially beneficial in cases where the feedstocks include solids in excess of about 25 micron size, or contain contaminants which increase the propensity for foulant
accumulation, such as olefinic or diolefinic species or oxygenated species. Moving bed
30 reactors utilizing downward-flowing liquid and gas can also be applied, as they would enable on-stream catalyst replacement.

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[0036] The catalyst used in the hydroprocessing stages should be a hydroprocessing catalyst suitable for aromatic saturation, desulfurization, denitrogenation or any combination thereof. Preferably, the catalyst is comprised of at least one Group VIII metal, optionally in combination with a Group VI metal, on an inorganic refractory support, which is preferably alumina or alumina-silica. The Group VIII and Group VI compounds are well known to those of ordinary skill in the art and are well defined in the Periodic Table of the Elements. For example, these compounds are listed in the Periodic Table found at the last page of Advanced Inorganic Chemistry, 2nd Edition 1966, Interscience Publishers, by Cotton and Wilkinson. The Group VIII metal is preferably present in an amount ranging from 2-20 wt.%, preferably 4-12 wt.%. Preferred Group VIII metals include Pt, Co, Ni, and Fe, with Pt, Co, and Ni being most preferred. The preferred Group VI metal is Mo which is present in an amount ranging from 5-50 wt.%, preferably 10-40 wt.%, and more preferably from 20-30 wt.%.

[0037] All metals weight percents given are on support. The term "on support" means that the percents are based on the weight of the support. For example, if a support weighs 100 g, then 20 wt.% Group VIII metal means that 20 g of the Group VIII metal is on the support.

[0038] Any suitable inorganic oxide support material may be used for the hydroprocessing catalyst of the present invention. Preferred are alumina and silica-alumina, including crystalline alumino-silicate such as zeolite. More preferred is alumina. The silica content of the silica-alumina support can be from 2-30 wt.%, preferably 3-20 wt.%, more preferably 5-19 wt.%. Other refractory inorganic compounds may also be used, non-limiting examples of which include zirconia, titania, magnesia, and the like. The alumina can be any of the aluminas conventionally used for hydroprocessing catalysts. Such aluminas are generally porous amorphous alumina having an average pore size from 50-200 Å, preferably 70-150 Å, and a surface area from 50-450 m²/g.

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- [0039] Following such hydroprocessing, the hydroprocessed cycle oil is conducted to the riser reactor for injection into the second reaction zone wherein the cycle oil is cracked into lower molecular weight cracked products and undesirable hydrogen transfer reactions are suppressed. In addition to LCCO, cracked products formed in the riser reactor include naphtha in amounts ranging from about 15 wt.% to about 75 wt.%, butanes in amounts ranging from about 2 wt.% to about 20 wt.%, butenes in amounts ranging from about 3 wt.% to about 20 wt.%, propane in amounts ranging from about 0.5 wt.% to about 7.5 wt.%, and propylene in amounts ranging from about 5 wt.% to about 35 wt.%. All wt.% are based on the total weight of the cracked product. In a preferred embodiment, at least 90 wt.% of the cracked products have boiling points less than 220°C. While not wishing to be bound by any theory, it is believed that the substantial concentration of propylene in the cracked product results from the hydroprocessed LCCO cracking in the second reaction zone.
- [0040] As used herein, cycle oil includes heavy cycle oil, light cycle oil, and mixtures thereof. Heavy cycle oil refers to a hydrocarbon stream boiling in the range of 240°C to 370°C (about 465°F to about 700°F). Light cycle oil refers to a hydrocarbon stream boiling in the range of 190°C to 240°C (about 375°F to about 465°F) . Naphtha includes light cat naphtha which refers to a hydrocarbon stream having a final boiling point less than about 190°C (375°F) and containing olefins in the C₅ to C₉ range, single ring aromatics (C₆ - C₉) and paraffins in the C₅ to C₉ range.

EXAMPLES

Example 1

[0041] A calculated comparison of cycle oil injection for re-cracking in an FCC reaction zone is set forth in Table 1. Conditions included a riser outlet temperature ("R.O.T.") of about 525°C (977°F) and a cat to oil ratio of about 6.6 on a total feed basis. Simulations 1, 2, 3, and 4 are compared to a "base case" FCC process with no cycle oil recycle. In case 1, cycle oil is separated from the FCC products and recycled to the FCC process via injection with the primary feed. In case 2, recycled cycle oil is injected upstream of main feed injection. In case 3, the cycle oil is injected upstream of main feed injection as in case 2, and the cycle oil is hydrogenated in order to produce a significant amount of tetralins (Table 2, column 1) prior to upstream injection. Accordingly, the hydrogenation of case 3 is under resulting in little if any conversion to decalins of aromatic species present in the cycle oil. In case 4, the cycle oil is hydrotreated under conditions sufficient to convert a significant amount of the cycle oil's aromatic species to decalins (Table 2, column 2). In all cases, a conventional large pore zeolite catalytic cracking catalyst was present in the reaction zone. No shape selective zeolite was employed. The table shows that some advantageous increase in propylene yield occurs when the cycle oil is injected with the primary feed (cases 0 and 1). Case 2 shows that a further increase in propylene yield accrues when, in accordance with this invention, the cycle oil is injected to a second reaction zone upstream of the first injection zone. Cases 3 and 4 show that additional propylene yield may be obtained via cycle oil hydroprocessing prior to injection.

25 [0042] Moreover, direct comparison of cases 3 and 4 shows that hydroprocessing under conditions that produce significant conversion to decalins results in greater propylene yield without a loss in naphtha yield, less coke make,

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and a nearly 100% increase in cycle oil conversion. While not wishing to be bound, it is believed that the large increase in cycle oil conversion in case 4 results in a suppression of undesirable hydrogen transfer reactions present in case 3 that convert species such as tetralins into naphthalene in the FCC's upstream reaction zone.

Table 1

R.O.T. = 977°F, Cat/Oil = 6.6 (TF basis), 26 kB/D FF Rate					
CASE	BASE	1	2	3	4
HCO Recycle, kB/D	0	2.3	2.3	2.3	2.3
Injection Location		Main Fd.	Pre-Inj.	Pre-Inj.	Pre-Inj.
Yields, Wt.% FF					
C ₂ - Dry Gas	2.93	2.99	3.18	3.2	3.34
C ₃ =	3.94	3.99	4.09	4.09	4.33
C ₄ =	5.41	5.53	5.67	5.72	6.03
LPG	13.46	13.8	14.06	14.2	15.05
Naphtha	46.39	48.33	45.5	45.85	48.85
LCO	5.93	5.86	6.94	7.02	6.54
HCO	16.39	13.59	13.3	12.91	9.66
BTMS	9.37	9.32	11.18	11.08	10.94
Coke	4.83	5.41	5.11	5.07	4.9
430°F (221°C) Conversion	72	74.7	72.2	73.2	77.1
% HCO Converted	0	31	34	38	73

Example 2

[0043] In accordance with a preferred embodiment, this example describes hydroprocessing a cycle oil stream and then injecting it at a point in a FCC riser reactor below (upstream of) the normal VGO feed injectors. This provides a high temperature, high cat/oil ratio, short residence time region wherein the hydrotreated cycle oil may be converted to naphtha and light olefins. Catalytic cracking conditions in the second reaction zone include temperatures ranging from about 1000-1350°F, cat/oil ratios of

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25-150 (wt/wt), and vapor residence times of 0.1-1.0 seconds in the pre-injection zone, as set forth in Table 3. Conventional catalytic cracking conditions were used in the first reaction zone, with temperature ranging from about 950 to about 1050 °F and the cat/oil ratio ranging from about 4 to about 10.

- 5 [0044] In this example, the cycle oils were hydrogenated to produce a significant amount of tetralins (Table 2, column 1) or under different hydrogenation conditions to produce significant amounts of decalins (Table 2, column 2) prior to upstream injection into the FCC unit. As set forth in Table 2, hydrogenation conditions to form decalins result in nearly complete saturation of aromatic species present in the
- 10 cycle oil.

Table 2

	Hydrogenation to form tetralins	Hydrogenation to form decalins
Conditions		
Catalyst	NiMo/Al ₂ O ₃	Pt/Al ₂ O ₃
Temperature °F/°C	700/371	550/288
Pressure (psig)	1200	1800
LHSV	0.7	1.7
H ₂ Treat Gas Rate (SCF/B)	5500	5000
Product Properties		
Boiling Point Distribution		
0.5 wt.% °F/°C	224.6/107	219.7/104
50.0 wt.% °F/°C	513.4/267	475.5/246
99.5 wt.% °F/°C	720.4/382	725.4/385
Gravity (°API)	26.2	33.2
Total Aromatics (wt.%)	57.6	0.6
One-Ring Aromatics (wt.%)	43.1	0.6
Feedstock Properties		
Boiling Point Distribution		
0.5 wt.% °F/°C	299.8/149	224.6/107
50.0 wt.% °F/°C	564.9/296	513.4/267
99.5 wt.% °F/°C	727.8/387	720.4/382
Gravity (°API)	13.8	26.2
Total Aromatics (wt.%)	83.5	57.6
One-Ring Aromatics (wt.%)	9.7	43.1

[0045] Cracking conditions for the pre-injected hydroprocessed cycle oil in the presence of catalytic cracking catalyst mixtures of large pore zeolite catalyst and large pore zeolite catalyst in combination with shape selective
5 zeolite catalysts such as ZSM-5 in a Microactivity Test Unit ("MAT") are set forth in Table 3.

[0046] MAT tests and associated hardware are described in Oil and Gas 64, 7, 84, 85, 1966, and Oil and Gas, November 22, 1971, 60-68. Conditions used herein included temperature 550, 650°C, run time 0.5 sec., catalyst charge
10 4.0 g, feed volume 0.95-1.0 cm³, and cat/oil ratio 4.0-4.2.

[0047] Catalysts A and B are commercially available, conventional, large pore FCC catalysts containing Y-zeolite, while catalyst C is a ZSM-5-containing catalyst.

[0048] As shown in Table 3, hydrogenation to form a significant amount
15 of decalins prior to pre-injection results in increased FCC conversion (column 2) compared to pre-injection of a cycle oil that was subjected to hydrogenation under different conditions to form a significant amount of tetralins and then pre-injected and cracked under similar conditions (column 1). Moreover, further increases in propylene production can be obtained when a shape selective
20 catalyst is combined with large pore FCC catalyst, as shown in column 3.

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Table 3

Feedstock	Hydroprocessed to form tetralins	Hydroprocessed to form decalins	Hydroprocessed to form decalins
Catalyst (steamed)	A	A	90% B 10% C
Temp., °F/°C	1020/550	1020/550	1200/650
Cat Oil	3.96	4.15	3.98
Conversion	81.2	93.3	89.1
Yields, wt. %			
C ₂ - Dry Gas	3.5	3.3	9.5
Propylene	5.4	7.1	13.3
Propane	1.9	2.3	0.9
Butenes	4.2	4.5	10.7
Butanes	8.8	13.2	3.0
Naphtha	53.2	59.8	48.4
430°F+	18.8	6.7	10.9
Coke	4.3	3.1	3.3

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CLAIMS:

1. A method for catalytically cracking a primary feed comprising the continuous steps of:

5 (a) injecting the primary feed into an FCC riser reactor having at least a first reaction zone and a second reaction zone upstream of the first reaction zone, the primary feed being injected into the first reaction zone;

(b) cracking the primary feed in the first reaction zone under catalytic cracking conditions in the presence of a catalytically effective amount of a regenerated zeolite-containing catalytic cracking catalyst in order to form at least
10 spent catalyst and a cracked product;

(c) separating at least a cycle oil from the cracked product and then processing at least a portion of the cycle oil in the presence of a catalytically effective amount of a hydroprocessing catalyst under hydroprocessing conditions in order to form a hydroprocessed cycle oil containing a significant amount of
15 decalins;

(d) injecting the hydroprocessed cycle oil into the second reaction zone; and

(e) cracking the hydroprocessed cycle oil under cycle oil catalytic cracking conditions in the presence of the catalytic cracking catalyst.

20 2. The method of claim 1 wherein the primary feed is at least one of hydrocarbonaceous oils boiling in the range of about 220°C to about 565°C; naphtha; gas oil; heavy hydrocarbonaceous oils boiling above 565°C; heavy and reduced petroleum crude oil; petroleum atmospheric distillation bottoms; petroleum vacuum distillation bottoms; pitch; asphalt; bitumen; tar sand oils;
25 shale oil; and liquid products derived from coal and natural gas.

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3. The method of claim 1 wherein conditions in the first reaction zone include temperatures from about 450° C to about 650°C, hydrocarbon partial pressures from about 10 to 40 psia, a primary feed residence time of less than about 20 seconds, and a catalyst to primary feed (wt/wt) ratio from about 3 to 12,
5 where catalyst weight is total weight of the catalyst composite.

4. The method of claim 3 wherein steam is concurrently introduced with the primary feed into the first reaction zone.

5. The method of claim 1 wherein conditions in the riser reactor's second reaction zone include temperatures from about 550°C to about 700°C,
10 hydrocarbon partial pressures from about 10 to 40 psia, a cycle oil residence time of less than about 10 seconds, and a catalyst to cycle oil (wt/wt) ratio from about 5 to 100, where catalyst weight is total weight of the catalyst composite.

6. The method of claim 5 wherein steam is concurrently introduced with the cycle oil feed into the second reaction zone.

15 7. The method of claim 1 wherein the hydroprocessing is performed in a single hydroprocessing stage at a temperature ranging from about 200°C to about 550°C, a reaction pressure ranging from about 1000 to about 3000 psig, a space velocity ranging from about 0.1 to 6 V/V/Hr, and a hydrogen charge rate ranging from about 1,000 to about 15,000 standard cubic feet per barrel
20 (SCF/B).

8. The method of claim 1 wherein the hydroprocessing is performed in a first hydroprocessing stage and a second hydroprocessing stage, the first hydroprocessing stage being upstream of the second hydroprocessing stage, wherein:

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(a) hydroprocessing conditions in the first stage include single hydroprocessing stage at a temperature ranging from about 200°C to about 550°C, a reaction pressure ranging from about 1000 to about 3000 psig, a space velocity ranging from about 0.1 to 6 V/V/Hr, and a hydrogen charge rate ranging from about 1,000 to about 15,000 standard cubic feet per barrel (SCF/B), and

(b) hydroprocessing conditions in the second stage include a temperature ranging from about 100°C to about 600°C, a reaction pressure ranging from about 100 to about 3000 psig, a space velocity ranging from about 0.1 to 6 V/V/Hr, and a hydrogen charge rate ranging from about 500 to about 15,000 standard cubic feet per barrel (SCF/B), more preferably from about 500 to about 10,000 SCF/B.

9. The method of claim 1 further comprising conducting the partially spent catalyst to a stripping zone and removing strippable hydrocarbons in order to form stripped, spent catalyst, and then conducting the stripped spent catalyst to a regeneration zone for regenerating the spent catalyst under FCC catalyst regeneration conditions in order to form the regenerated, zeolite-containing, catalytic cracking catalyst.

10. The method of claim 9 further comprising separating propylene from the cracked product and then polymerizing the propylene in order to form polypropylene.