

Claims

1. A process for the catalytic cracking of hydrocarbon oils, comprising the step of contacting a hydrocarbon oil feedstock, particularly a heavy feedstock oil, with a catalytic cracking catalyst for reaction in a reactor comprising one or more fast fluidized reaction zones, wherein at least one of the fast fluidized reaction zones of the reactor is a full dense-phase reaction zone, and the axial solid fraction ϵ of the catalyst is controlled within a range of about 0.1 to about 0.2 throughout the full dense-phase reaction zone.

2. The process according to claim 1, which is used for the production of light olefins from heavy feedstock oils, and further comprises the steps of:

i) contacting the heavy feedstock oil, such as an inferior heavy oil, with the catalytic cracking catalyst in the full dense-phase reaction zone of the reactor for reaction under conditions effective to produce light olefins, wherein the axial solid fraction ϵ of the catalyst is controlled within a range of about 0.1 to about 0.2 throughout the full dense-phase reaction zone of the reactor;

ii) separating the reaction effluent from the reactor to obtain a reaction product rich in light olefins and a spent catalyst;

iii) regenerating the spent catalyst and recycling at least a portion of the resulting regenerated catalyst to step i) as the catalytic cracking catalyst; and

iv) optionally, separating the reaction product to obtain dry gas, liquefied petroleum gas, naphtha, diesel and slurry.

3. The process according to claim 2, wherein the process further comprises, prior to said step i) and/or after said step ii), one or more additional reaction steps selecting from catalytic cracking and catalytic isomerization carried out in other types of reaction zones selected from a dilute-phase transport fluidized bed, a dense-phase fluidized bed, and a

conventional fast fluidized bed.

4. The process according to any one of the preceding claims, further comprising: introducing one or more streams of supplementary catalyst into the full dense-phase reaction zone at a position downstream of the position where the catalytic cracking catalyst is introduced into the full dense-phase reaction zone, and contacting the supplementary catalyst with the material in the full dense-phase reaction zone for catalytic cracking reaction,

wherein the one or more streams of supplementary catalyst each independently has a carbon content of about 0-1.0 wt%, and is each independently selected from regenerated, spent or semi-regenerated catalytic cracking catalysts, and the total amount of the one or more streams of supplementary catalyst accounts for about 0-50 wt%, preferably about 5-45 wt%, more preferably about 10-40 wt%, of the catalyst circulation rate of the reactor,

the one or more streams of supplementary catalyst is each independently introduced at a height within the range of from greater than 0% to about 90%, preferably about 20-80%, more preferably about 30-75%, of the total height of the full dense-phase reaction zone.

5. The process according to any one of the preceding claims, further comprising: introducing a C4 hydrocarbon fraction and/or a C5-C6 light gasoline fraction into the reactor at one or more positions for catalytic cracking reaction;

preferably, at least a portion of the C4 hydrocarbon fraction and/or C5-C6 light gasoline fraction is introduced at a position upstream of the position where the hydrocarbon oil feedstock is introduced into the reactor.

6. The process according to any one of the preceding claims, wherein the catalytic cracking catalyst comprises, based on the dry weight of the catalytic cracking catalyst, about 1-50 wt%, preferably about 5-45 wt%, more preferably about 10-40 wt%, of a zeolite; about 5-99 wt%,

preferably about 10-80 wt%, more preferably about 20-70 wt%, of an inorganic oxide, and about 0-70 wt%, preferably about 5-60 wt%, more preferably about 10-50 wt%, of a clay;

wherein the zeolite comprises a mesopore zeolite selected from the group consisting of ZSM zeolites, ZRP zeolites, and combinations thereof, and optionally a macropore zeolite selected from the group consisting of rare earth exchanged Y-type zeolite, rare earth exchanged HY type zeolite, ultrastable Y-type zeolite, high-silica Y-type zeolite, and combinations thereof;

preferably, the mesopore zeolite accounts for about 0-50 wt%, preferably about 0-20 wt%, of the total weight of the zeolite on a dry weight basis.

7. The process according to any one of the preceding claims, wherein the reaction conditions in the full dense-phase reaction zone include: a reaction temperature of about 510-700 °C, a reaction time of about 1-20 seconds, a catalyst-to-oil weight ratio of about 3 : 1 to about 50 : 1, a water-to-oil weight ratio of about 0.03 : 1 to about 0.8 : 1, a catalyst density of about 120-290 kg/m³, a vapor velocity of about 0.8-2.5 m/s, a reaction pressure of about 130-450 kPa, and a catalyst mass flow rate, G_s , of about 15-150 kg/(m²·sec);

preferably, the reaction conditions in the full dense-phase reaction zone include: a reaction temperature of about 550-650 °C, a reaction time of about 3-15 seconds, a catalyst-to-oil weight ratio of about 10 : 1 to about 30 : 1, a water-to-oil weight ratio of about 0.05 : 1 to about 0.5 : 1, a catalyst density of about 150-250 kg/m³, a vapor velocity of about 1-1.8 m/s, a reaction pressure of about 130-450 kPa, and a catalyst mass flow rate, G_s , of about 20-130 kg/(m²·sec).

8. The process according to any one of the preceding claims, wherein the hydrocarbon oil feedstock is a heavy feedstock oil, the properties of which meet at least one of the following criteria: a density at 20 °C of about 850-1000 kg/m³, a carbon residue of about 2-10 wt%, a total nickel

and vanadium content of about 2-30 ppm, and a characterization factor K of less than about 12.1;

preferably, the properties of the heavy feedstock oil meet at least one of the following criteria: a density at 20 °C of about 890-940 kg/m³, a carbon residue of about 2-8 wt%, a total nickel and vanadium content of about 5-20 ppm, and a characterization factor K of less than about 12.0.

9. The process according to any one of the preceding claims, wherein the hydrocarbon oil feedstock is a heavy feedstock oil selected from heavy petroleum hydrocarbons, other mineral oils, and combinations thereof;

wherein the heavy petroleum hydrocarbon is selected from the group consisting of vacuum residuum, inferior atmospheric residuum, inferior hydrogenated residuum, coker gas oil, deasphalted oil, vacuum gas oil, high acid value crude oil, high metal crude oil, and combinations thereof; and

said other mineral oil is selected from the group consisting of coal liquefaction oil, oil sand bitumen, shale oil, and combinations thereof.

10. A reactor useful for catalytic cracking of hydrocarbon oils, particularly heavy feedstock oils, comprises, from bottom to top, an optional pre-lifting section, a full dense-phase reaction zone, a transition section and an outlet zone, wherein the full dense-phase reaction zone is in the form of an equal-diameter or varied-diameter hollow column with a roughly circular cross section, an open bottom end and an open top end, the optional pre-lifting section is in communication with the bottom end of the full dense-phase reaction zone, the top end of the full dense-phase reaction zone is in communication with the outlet zone through the transition section, the optional pre-lifting section and/or the bottom of the full dense-phase reaction zone is provided with at least one catalytic cracking catalyst inlet, and the optional pre-lifting section and/or the bottom of the full dense-phase reaction zone is provided with at least one feedstock inlet,

wherein the cross-sectional diameter of the bottom end of the full dense-phase reaction zone is greater than or equal to the diameter of the optional pre-lifting section and the cross-sectional diameter of the top end of the full dense-phase reaction zone is greater than the diameter of the outlet zone, and the side wall of the full dense-phase reaction zone is provided with one or more inlets for supplementary catalyst, each independently disposed at a height within the range of from greater than 0% to about 90%, preferably about 20-80%, more preferably about 30-75%, of the total height of the full dense-phase reaction zone.

11. The reactor according to claim 10, wherein the reactor further comprises one or more reaction zones of other forms selected from a dilute-phase transport fluidized bed, a dense-phase fluidized bed, and a conventional fast fluidized bed, at the upstream of the full dense-phase reaction zone, preferably between the optional pre-lifting section and the full dense-phase reaction zone, and/or at the downstream of the full dense-phase reaction zone, preferably between the transition section and the outlet zone.

12. The reactor according to claim 10 or 11, wherein the full dense-phase reaction zone is in the form of an equal-diameter hollow cylinder, or a hollow column having a diameter increases continuously or discontinuously from bottom to top, such as in the form of an inverted hollow truncated cone, a hollow column constituted by two or more cylinder sections with successively increased diameters, a hollow column constituted by two or more sections of inverted truncated cones with successively increased diameters, or a hollow column constituted by one or more cylinder sections and one or more sections of inverted truncated cones;

preferably, the bottom of the full dense-phase reaction zone is provided with a catalyst distribution plate.

13. The reactor according to any one of claims 10 to 12, wherein the pre-lifting section has a diameter of about 0.2-5 meters, preferably about

0.4-4 meters, more preferably about 0.6-3 meters; and a ratio of its height to the total height of the reactor of about 0.01 : 1 to about 0.2 : 1, preferably about 0.03 : 1 to about 0.18 : 1, more preferably about 0.05 : 1 to about 0.15 : 1.

5 14. The reactor according to any one of claims 10 to 13, wherein the ratio of the diameter of the maximum cross-section of the full dense-phase reaction zone to the total height of the reactor is about 0.005 : 1 to about 1 : 1, preferably about 0.01 : 1 to about 0.8 : 1, more preferably about 0.05 : 1 to about 0.5 : 1; and the ratio of the height of the full
10 dense-phase reaction zone to the total height of the reactor is about 0.1 : 1 to about 0.9 : 1, preferably about 0.15 : 1 to about 0.8 : 1, more preferably about 0.2 : 1 to about 0.75 : 1.

15 15. The reactor according to any one of claims 10 to 14, wherein the full dense-phase reaction zone is in the form of an inverted hollow truncated cone with a longitudinal section of an isosceles trapezoid, which has a bottom cross-sectional diameter of about 0.2-10 meters, preferably about 0.5-8 meters, more preferably about 1-5 meters; a ratio of the top cross-sectional diameter to the bottom cross-sectional diameter of from greater than 1 to about 50, preferably about 1.2 to about 10, more
20 preferably about 1.5 to about 5; and a ratio of the diameter of the maximum cross-section to the total height of the reactor of about 0.005 : 1 to about 1 : 1, preferably about 0.01 : 1 to about 0.8 : 1, more preferably about 0.05 : 1 to about 0.5 : 1; and the ratio of the height of the full dense-phase reaction zone to the total height of the reactor is about 0.1 : 1
25 to about 0.9 : 1, preferably about 0.15 : 1 to about 0.8 : 1, more preferably about 0.2 : 1 to about 0.75 : 1.

30 16. The reactor according to any one of claims 10 to 14, wherein the full dense-phase reaction zone is in the form of a hollow column consisting of, from bottom to top, a section of an inverted truncated cone and a cylinder section, wherein the truncated cone has a longitudinal section of an isosceles trapezoid, a bottom cross-sectional diameter of

about 0.2-10 meters, preferably about 0.5-8 meters, more preferably about 1-5 meters; a ratio of the top cross-sectional diameter to the bottom cross-sectional diameter of from greater than 1 to about 50, preferably about 1.2 to about 10, more preferably about 1.5 to about 5; the diameter of the cylinder is approximately the same as top cross-sectional diameter of the truncated cone, the ratio of the height of the cylinder to the height of the truncated cone is about 0.4 : 1 to about 2.5 : 1, preferably about 0.8 : 1 to about 1.5 : 1; the ratio of the diameter of the maximum cross-section of the full dense-phase reaction zone to the total height of the reactor is about 0.005 : 1 to about 1 : 1, preferably about 0.01 : 1 to about 0.8 : 1, more preferably about 0.05 : 1 to about 0.5 : 1; and the ratio of the height of the full dense-phase reaction zone to the total height of the reactor is about 0.1 : 1 to about 0.9 : 1, preferably about 0.15 : 1 to about 0.8 : 1, more preferably about 0.2 : 1 to about 0.75 : 1.

17. The reactor according to any one of claims 10 to 14, wherein the full dense-phase reaction zone is in the form of a hollow cylinder having a diameter of about 0.2-10 meters, preferably about 1-5 meters, and the ratio of the diameter of the full dense-phase reaction zone to the total height of the reactor is about 0.005 : 1 to about 1 : 1, preferably about 0.01 : 1 to about 0.8 : 1, more preferably about 0.05 : 1 to about 0.5 : 1, and the ratio of the height of the full dense-phase reaction zone to the total height of the reactor is about 0.1 : 1 to about 0.9 : 1, preferably about 0.15 : 1 to about 0.8 : 1, more preferably about 0.2 : 1 to about 0.75 : 1, preferably, the bottom of the full dense-phase reaction zone is provided with a catalyst distribution plate.

18. The reactor according to any one of claims 10 to 17, wherein the ratio of the height of the transition section to the total height of the reactor is about 0.01 : 1 to about 0.1 : 1, preferably about 0.02 : 1 to about 0.05 : 1; preferably, the transition section is in the form of a hollow truncated cone with a longitudinal section of an isosceles trapezium with sides

having an internal inclination angle α of about 25-85°, preferably about 30-75°.

19. The reactor according to any one of claims 10 to 18, wherein the outlet zone has a diameter of about 0.2-5 meters, preferably about 0.4-4
5 meters, more preferably about 0.6-3 meters, and a ratio of its height to the total height of the reactor of about 0.05 : 1 to about 0.2 : 1, preferably about 0.08 : 1 to about 0.18 : 1, more preferably about 0.1 : 1 to about 0.15 : 1, more preferably about 0.1 : 1 to about 0.15 : 1, and the outlet end of the outlet zone can be open or can be directly connected with the inlet
10 of the cyclone.

20. The reactor according to any one of claims 10 to 19, wherein the at least one feedstock inlets is each independently disposed on the pre-lifting section at a position with a distance from its outlet end of less than or equal to about 1/3 of the height of the pre-lifting section, at the
15 outlet end of the pre-lifting section, or at the bottom of the full dense-phase reaction zone,

optionally, when a feedstock inlet is provided at the bottom of the full dense-phase reaction zone, a gas distributor may be provided at said feedstock inlet.

21. A system useful for catalytic cracking of hydrocarbon oils, particularly heavy feedstock oils, comprises a catalytic cracking reactor, a catalyst separation device, an optional reaction product separator, and a regenerator,
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wherein the catalytic cracking reactor is provided with a catalyst
25 inlet at the bottom, a feedstock inlet at the lower part and an outlet at the top, the catalyst separation device is provided with an inlet, a catalyst outlet and a reaction product outlet, the optional reaction product separator is provided with a reaction product inlet, a dry gas outlet, a liquefied petroleum gas outlet, a naphtha outlet, a DIESEL outlet and a
30 slurry outlet, and the regenerator is provided with a catalyst inlet and a catalyst outlet,

the catalyst inlet of the catalytic cracking reactor is in fluid communication with the catalyst outlet of the regenerator, the outlet of the catalytic cracking reactor is in fluid communication with the inlet of the catalyst separation device, the reaction product outlet of the catalyst
5 separation device is in fluid communication with the reaction product inlet of the optional reaction product separator, the catalyst outlet of the catalyst separation device is in fluid communication with the catalyst inlet of the regenerator,

wherein the catalytic cracking reactor comprises a reactor according
10 to any one of claims 10 to 20.