

Claims

1. A process for 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 a dilute-phase transport fluidized bed and a fast fluidized bed connected in series, wherein, in the fast fluidized bed, the axial solid fraction ε of the catalyst is controlled within the range of about 0.1 to about 0.2.

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

i) contacting a first feedstock comprising a light feedstock and/or a heavy feedstock oil with the catalytic cracking catalyst in the dilute-phase transport fluidized bed to carry out a first catalytic cracking reaction; and

ii) subjecting the reaction effluent from step i) and optionally a second feedstock comprising a light feedstock and/or a heavy feedstock oil to a second catalytic cracking reaction in the fast fluidized bed,

wherein the light feedstock is selected from the group consisting of a C4 hydrocarbon fraction, a C5-C6 light gasoline fraction, and combinations thereof, and at least one of the first and second feedstocks comprises the heavy feedstock oil;

wherein the axial solid fraction ε of the catalyst in the fast fluidized bed is controlled within the range of about 0.1 to about 0.2.

3. The process according to claim 2, further comprising the steps of:

i) contacting the first feedstock with the catalytic cracking catalyst in the dilute-phase transport fluidized bed to carry out the first catalytic cracking reaction;

ii) subjecting the reaction effluent from step i) and optionally the second feedstock to the second catalytic cracking reaction in the fast fluidized bed under conditions effective to produce light olefins, wherein

the axial solid fraction ε of the catalyst in the fast fluidized bed is controlled within the range of about 0.1 to about 0.2;

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

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

v) optionally, separating the reaction product to obtain dry gas, liquefied petroleum gas, gasoline, diesel oil and slurry

10 4. The process according to any of the preceding claims, further comprising: introducing one or more streams of supplementary catalyst into the fast fluidized bed, and contacting the supplementary catalyst with the material in the fast fluidized bed to carry out a catalytic cracking reaction,

15 wherein the one or more streams of supplementary catalyst each independently has a carbon content of about 0-1.0 wt.%, and each independently is selected from regenerated, semi-regenerated, or spent catalytic cracking catalysts, and the total amount of the one or more streams of supplementary catalyst accounts for about 0-50 wt.%,
20 preferably about 5-30 wt.%, of the catalyst circulation rate of the reactor;

the one or more streams of supplementary catalyst are each independently introduced at about 0-90%, preferably about 20-80%, more preferably about 30-75%, of the total height of the fast fluidized bed.

5 5. The process according to any of the preceding claims, wherein the
25 catalytic cracking catalyst comprises, based on the dry weight of the catalytic cracking catalyst, from about 1 wt% to about 50 wt%, preferably from about 5 wt% to about 45 wt%, more preferably from about 10 wt% to about 40 wt%, of a zeolite, from about 5 wt% to about 99 wt%, preferably from about 10 wt% to about 80 wt%, more preferably from about 20 wt%
30 to about 70 wt%, of an inorganic oxide, and from about 0 wt% to about 70 wt%, preferably from about 5 wt% to about 60 wt%, more preferably from

about 10 wt% to about 50 wt%, of a clay;

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
5 earth exchanged Y-type zeolites, rare earth exchanged H-Y type zeolites, ultrastable Y-type zeolites, high-silica Y-type zeolites, and combinations thereof;

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

6. The process according to any of claims 2-5, wherein the conditions for the first catalytic cracking reaction include: a reaction temperature of about 500-600 °C, a reaction time of about 0.05-5 seconds, a catalyst-to-oil weight ratio of about 1 : 1 to about 50 : 1, a water-to-oil weight ratio of
15 about 0.03 : 1 to about 0.5 : 1, a catalyst density of about 20-100 kg/m³, a vapor velocity of about 4-18 m/s, a reaction pressure of about 130-450 kPa, and a catalyst mass flow rate G_s of about 180-500 kg/(m²·s),

preferably, the conditions for the first catalytic cracking reaction include: a reaction temperature of about 520-580 °C, a reaction time of
20 about 1-3 seconds, a catalyst-to-oil weight ratio of about 5 : 1 to about 25 : 1, and a water-to-oil weight ratio of about 0.05 : 1 to about 0.3 : 1; and

the conditions for the second catalytic cracking reaction include: a reaction temperature of about 510-650 °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-
25 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·s),

preferably, the conditions for the second catalytic cracking reaction
30 include: a reaction temperature of about 550-620 °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·s).

5 7. The process according to any of the preceding claims, wherein the heavy feedstock oil is an inferior heavy oil, the properties of which meet at least one of the following criteria: a density at 20 °C of about 900-1000 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
10 about 12.1;

 preferably, meet at least one of the following criteria: a density at 20 °C of about 910-940 kg/m³, a carbon residue of about 3-8 wt%, a total nickel and vanadium content of about 5-20 ppm, and a characterization factor K of less than about 12.0.

15 8. The process according to any of the preceding claims, wherein the heavy feedstock oil is an inferior heavy 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
20 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.

25 9. The process according to any of claims 2-8, wherein at least one of the first and second feedstocks comprises the light feedstock selected from the group consisting of a C4 hydrocarbon fraction, a C5-C6 light gasoline fraction, and combinations thereof;

 preferably, the first feedstock comprises the light feedstock and the
30 heavy feedstock oil, and at least a portion of the light feedstock is introduced into the dilute-phase transport fluidized bed at the upstream of

the position where the heavy feedstock oil is introduced into the dilute-phase transport fluidized bed;

preferably, the first feedstock comprises the heavy feedstock oil, and the second feedstock comprises the light feedstock; or

5 preferably, the first feedstock comprises the light feedstock, and the second feedstock comprises the heavy feedstock oil.

10. The process according to any of the preceding claims, wherein the fast fluidized bed comprises, from bottom to top, a full dense-phase reaction zone and a transition section, the full dense-phase reaction zone is
10 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 dilute-phase transport fluidized bed 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 section of
15 the reactor via the transition section, the bottom of the full dense-phase reaction zone is optionally provided with one or more inlets for feeding the second feedstock,

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
20 dilute-phase transport fluidized bed and the cross-sectional diameter of the top end of the full dense-phase reaction zone is greater than the diameter of the outlet section, and the bottom or the side wall of the full dense-phase reaction zone is provided with one or more inlets for supplementary catalyst, each independently disposed at about 0-90%, preferably about 20-
25 80%, more preferably about 30-75%, of the total height of the fast fluidized bed.

11. The process according to claim 10, 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
30 discontinuously from bottom to top, such as 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.

5 12. A system useful for catalytic cracking of hydrocarbon oils, particularly heavy feedstock oils, comprising a catalytic cracking reactor, a catalyst separation device, an optional reaction product separator, and a regenerator,

10 wherein the catalytic cracking reactor comprises a dilute-phase transport fluidized bed and a fast fluidized bed connected in series, with the dilute-phase transport fluidized bed being in fluid communication with the fast fluidized bed and disposed at the upstream of the fast fluidized bed, along the flow direction of the reaction stream;

15 the dilute-phase transport fluidized bed is provided with a catalyst inlet at the bottom and a first feedstock inlet at the lower part, the fast fluidized bed is provided with an outlet at the top and an optional second feedstock inlet at the bottom, 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
20 gas outlet, a liquefied petroleum gas outlet, a gasoline outlet, a diesel oil outlet and a slurry outlet, and the regenerator is provided with a catalyst inlet and a catalyst outlet,

25 the catalyst inlet of the dilute-phase transport fluidized bed is in fluid communication with the catalyst outlet of the regenerator, the outlet of the fast fluidized bed is in fluid communication with the inlet of the catalyst separation device, the reaction product outlet of the catalyst separation device is in fluid communication with the reaction product inlet of the optional reaction product separator, and the catalyst outlet of the catalyst separation device is in fluid communication with the catalyst inlet of the
30 regenerator,

wherein the fast fluidized bed comprises a full dense-phase reaction

zone and a transition section in sequence from bottom to top, 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 dilute-phase transport fluidized bed 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 section of the reactor through the transition section, the bottom of the full dense-phase reaction zone is optionally provided with one or more second feedstock inlets,

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 dilute-phase transport fluidized bed and the cross-sectional diameter of the top end of the full dense-phase reaction zone is greater than the diameter of the outlet section, and the bottom or the side wall of the full dense-phase reaction zone is provided with one or more inlets for supplementary catalyst, each independently disposed at about 0-90%, preferably about 20-80%, more preferably about 30-75%, of the total height of the fast fluidized bed.

13. The system according to claim 12, wherein the fast fluidized bed is coaxially arranged with the dilute-phase transport fluidized bed, and the fast fluidized bed is disposed above the dilute-phase transport fluidized bed,

preferably, the fast fluidized bed is provided with a catalyst distribution plate at the bottom, and/or a gas distributor is provided at the position of the second feedstock inlet.

~~14. The system according to claim 12 or 13, wherein the fast fluidized bed comprises a full dense-phase reaction zone and a transition section in sequence from bottom to top, 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 dilute-phase transport fluidized bed 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 section of the reactor through the transition section, the bottom of the full dense phase reaction zone is optionally provided with one or more second~~
5 ~~feedstock inlets,~~

~~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 dilute phase transport fluidized bed and the cross sectional diameter of the top end of the full dense phase reaction zone is greater than the diameter~~
10 ~~of the outlet section, and the bottom or the side wall of the full dense phase reaction zone is provided with one or more inlets for supplementary catalyst, each independently disposed at about 0-90%, preferably about 20-80%, more preferably about 30-75%, of the total height of the fast fluidized bed.~~

15 ~~1514.~~ The system according to claim ~~1412~~, 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 an inverted hollow truncated cone, a hollow column constituted by two or more cylinder sections with
20 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.

~~1615.~~ The system according to claim ~~1514~~, wherein the full dense-phase reaction zone is in the form of an inverted truncated cone with a
25 longitudinal section of an isosceles trapezoid, and has a bottom cross-sectional diameter of about 0.2-10 meters, preferably about 0.5-8 meters, more preferably about 1-5 meters; and a ratio of the top cross-sectional diameter to the bottom cross-sectional diameter of from greater than 1 to
30 about 50, preferably about 1.2 to about 10, more preferably about 1.5 to about 5; the ratio of the diameter of the maximum cross-section of the full

dense-phase reaction zone to the total height of the fast reaction bed 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; the ratio of the height of the full dense-phase reaction zone to the total height of the fast reaction
5 bed is about 0.1 : 1 to about 0.9 : 1, preferably about 0.3 : 1 to about 0.85 : 1, more preferably about 0.5 : 1 to about 0.8 : 1, and/or

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°, and the ratio
10 of the height of the transition section to the total height of the fast reaction bed is about 0.1 : 1 to about 0.9 : 1, preferably about 0.2 : 1 to about 0.5 : 1.