A reactor for the upgrade of heavy oil feedstock, i.e., in which a multi-phase mixture, including gas, a slurry catalyst, and volatile liquid, is to be conducted. The reactor includes a reaction chamber having a substantially unencumbered center portion through which the multi-phase mixture is conducted upwardly. In one embodiment, the downcomer includes a transport section having an interior comprised of inner and outer regions separated horizontally by a vertical barrier, and a baffle structure disposed on an inner surface of the barrier. In another embodiment, the reactor comprises a downcomer having an upper degassing section which includes a frusto-conical upper surface. The multi-phase mixture is caused to flow along the surface in a downward helical path, such that heavier components are centrifugally urged outwardly, and lighter components, e.g., gas, migrate inwardly. In one embodiment, the reactor comprises a distributor device disposed within for distributing the multi-phase mixture therein. The distributor device includes a first pipe adapted for conducting a gas phase, and including first discharge ports, a second pipe adapted for conducting a slurry or a liquid phase, and including second discharge ports, and a plurality of nozzles.
GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published: without international search report and to be republished upon receipt of that report.
REACTOR FOR HEAVY OIL UPGRADE AND METHOD OF USE

FIELD OF ART

[001] Disclosed a reactor for upgrading heavy oil feedstock and methods of use thereof.

BACKGROUND

[002] It has been proposed to upgrade heavy oil feedstock, i.e., heavy hydrocarbons, via hydroprocessing in which the hydrocarbons are admixed with an active catalyst composition in liquefied slurry form. Liquid recirculating reactors have been proposed for use with a multi-phase mixture, including a gas phase, plus a slurry and/or a liquid phase, wherein the multi-phase mixture is conducted upwardly within a reaction chamber and then recirculated back to the lower portion of the chamber, e.g., through a vertical downcomer disposed in the chamber. Such an upflow reactor is useful, for example, in the hydروprocessing of heavy hydrocarbons employing liquefied catalyst slurry and hydrogen gas as disclosed in U.S. Published Application No. 2007/0140927, a feed of heavy hydrocarbons and catalyst slurry is introduced into the lower portion of a reactor chamber, along with hydrogen in a gas phase. Those components travel upwardly within the chamber, enabling the hydrogen to react with, and hydrogenate, the hydrocarbons. Near an upper portion of the chamber, the hydrogenated hydrocarbons are removed as is excess hydrogen gas. The components of the mixture are initially introduced into the lower portion of the chamber and are distributed therein by a distribution tray. It is important to obtain a proper mixing of the components and achieve a high dispersion of the bubbles of the gas phase, to promote the reaction and establish proper flow patterns in the reactor.

[003] A flow of liquefied catalyst slurry and residual hydrogen gas is recirculated within the chamber through a vertically oriented downcomer in the chamber. Such a multi-phase mixture enters an upper end of the downcomer, for example, under the action of a recirculation pump. In the prior art, the downcomer
has traditionally been located coaxially in the center of the reaction chamber. The mixing which occurs in the downcomer tends to keep the catalyst concentration profile and the temperature profile generally uniform along the height of the reactor.

[004] It is desirable to separate gas from the multi-phase mixture descending through the downcomer, because the gas resists the downward flow of the mixture and reduces the efficiency of any pumps which can be provided to recirculate the mixture exiting the downcomer. Multi-phase mixture exiting the downcomer is recirculated, e.g., back into the reaction chamber or elsewhere. The recirculation is effected by a pump, the efficiency of which is reduced by the presence of gas bubbles in the mixture. Therefore, at or near its upper end the downcomer is typically provided with a degassing section, e.g., in the form of a generally frusto-conical pan which is upwardly open and leads downwardly to a usually cylindrical transport section of the downcomer. Due to the degassing section being of relatively large diameter, travel of the multi-phase mixture therein is slower than the natural ascension velocity of the hydrogen gas bubbles, thereby facilitating escape of the bubbles from the rest of the multi-phase flow.

[005] That bubble escape reduces the overall resistance to downward flow of the multi-phase mixture, increases pump efficiency, and improves mixing among other advantages. Notwithstanding those efforts, gas bubbles will still exit the downcomer and reduce the pump efficiency, or possibly even damage the pump. It would be desirable to yet further reduce the bubble content in the multi-phase mixture. It would also be desirable to further separate gas bubbles from the mixture being recirculated. Since the presence of the bubbles inhibits the downward flow of the mixture, it will be appreciated that promoting the escape of the bubbles from the rest of the multi-phase flow reduces the overall resistance to downward flow of the multi-phase mixture within the downcomer, among other advantages. It would be further desirable to yet further reduce the bubble content in the multi-phase mixture.

[006] In certain heavy oil upgrade operations, after going through the reaction process, the spent (or used) slurry catalyst becomes heavier. It would be desirable to further promote the separation of spent catalyst from the unreacted (fresh) catalyst before the mixture exits the downcomer, so that the slurry 44catalyst
can be re-directed for regeneration. It would be further desirable to enhance the mixing of the multi-phase components.

5

SUMMARY

[007] One aspect of the present disclosure relates to a reactor for heavy oil processing comprising a downcomer for downwardly conducting a multi-phase mixture. The downcomer comprises an interior in which is disposed a baffle structure arranged to induce the mixture to flow in a downward generally helical path such that denser components of the mixture are centrifugally urged outwardly away from a center of the downcomer and less dense components migrate toward the center.

[008] In an embodiment, the downcomer comprises a transport section having an interior comprised of inner and outer regions separated horizontally by a vertical barrier, and a baffle structure disposed on an inner surface of the barrier. The baffle structure is arranged to induce the mixture to flow in a downward generally helical path such that denser components of the mixture are centrifugally urged outwardly away from a center of the downcomer and less dense components migrate toward the center. The barrier includes openings enabling the denser components to travel from the inner region to the outer region to be collected herein.

[009] Another aspect of the present disclosure involves a method of separating components of a multi-phase mixture in a downcomer of a reactor, comprising: A. feeding the mixture into an interior of the downcomer; and B. inducing the mixture to flow in a downward, generally helical direction, wherein denser components are centrifugally urged away from a center of the interior, and less dense components migrate toward the center. In an embodiment, step A involves feeding the mixture into an inner region of the downcomer's interior, which inner region is separated by a barrier from an outer region of the downcomer's interior. Step B involves inducing the mixture to flow in a downward generally helical direction in the inner region, wherein denser components of the mixture are
centrifugally urged away from a center of the downcomer, and less dense
components migrate toward the center. In another embodiment, the process further
comprises admitting the centrifugally urged denser components into the outer region
through openings formed in the barrier.

[010] In another aspect, the present disclosure also pertains to a method
wherein the downcomer receives a mixture of heavy hydrocarbons, a catalyst slurry,
and hydrogen gas.

[011] In yet one aspect, the invention relates to a reactor in which a multi¬
phase mixture, including gas and a catalyst slurry or liquid, is to be conducted, the
reactor comprising: a reaction chamber having a substantially unencumbered center
portion through which the multi-phase mixture is conducted upwardly; a
downcomer arrangement disposed laterally outwardly of the center portion and
adjacent to an inner surface of the reaction chamber; and an external pump
communicating with a lower portion of the reaction chamber for circulating
components of the mixture downward from an upper end of the downcomer
arrangement to a lower end thereof.

[012] It is contemplated that a gas-containing pocket of the collection
chamber communicates with the reaction chamber independently of the pump, and
that the pump is connected to recycle the remaining components from the collection
chamber to the reaction chamber.

[013] In yet another aspect, the invention relates to a reactor for heavy oil
upgrade comprising a device for distributing a multi-phase mixture in a reactor. The
device includes a first pipe adapted for conducting a gas phase, a second pipe
adapted for conducting a slurry or a liquid phase, and a plurality of nozzles. Each
nozzle includes passages communicating the first and second pipes with a venturi
outlet of the nozzle such that pressurized gas phase from the first pipe passing
through the venturi outlet creates a negative pressure for drawing-in the slurry or the
liquid phase, wherein the slurry or the liquid phase is mixed with the gas phase in
the venturi outlet.

[014] In one aspect, the invention relates to a reactor in which the residence
time of the multi-phase mixture within the degassing section is increased by
promoting a coalescence of smaller bubbles to form larger bubbles having a faster natural ascension velocity. That effect is achieved by flowing the multi-phase mixture along a generally frusto-conical surface of the degassing section in a generally downwardly helical direction. Denser components of the mixture are centrifugally urged outwardly away from a center axis of the surface, and less dense components (e.g., gas) bubbles migrate toward the center axis. Small gas bubbles can then coalesce into larger bubbles which have a greater inherent tendency to rise. In one embodiment, baffles preferably placed along the surface to guide the mixture in the helical flow will maximize the residence time of the mixture on the surface and thus maximize the bubble escape.

[015] Also disclosed is a process for the hydro-conversion of heavy hydrocarbons in a reactor, comprising: providing a mixture of components including heavy hydrocarbons, catalyst, and hydrogen gas in a lower portion of a reaction chamber of the reactor; conducting the mixture upwardly in a substantially unencumbered center section of the reaction chamber, and then conducting at least the heavy hydrocarbons and catalyst components of the mixture by pumping those components downwardly through a downcomer arrangement disposed laterally of the center and near an inner surface of the reaction chamber.

[016] In one embodiment, the process comprises separating the hydrogen gas from the heavy hydrocarbons and catalyst after exiting the downcomer, and reintroducing the hydrogen gas into the lower portion of the reaction chamber separately from the heavy hydrocarbons and catalyst.

BRIEF DESCRIPTION OF THE FIGURES

[017] Figure 1 is a schematic side view of an embodiment of a reactor.
[018] Figure 2 is a fragmentary cut-away perspective view of an embodiment of a downcomer.
[019] Figure 3 is a cross sectional view through a transport section of an embodiment of a downcomer.
[020] Figure 4 is a fragmentary vertical sectional view showing an inclined floor of of an embodiment of a downcomer.
Figure 5 is a schematic vertical sectional view through a reaction chamber according to the present disclosure.

Figure 6A is a schematic fragmentary view of the reactor showing a valve in an open state.

Figure 6B is a view similar to Figure 5A showing the valve closed.

Figure 7A is a schematic top view of one embodiment of a distributor device.

Figure 7B is a vertical sectional view taken through the device of Figure 7A along the line Ib-Ib.

Figure 7C is a fragmentary side elevational view taken in the direction of arrow A in Figure 7A.

Figure 8 is a schematic side view of one embodiment of a reactor, e.g., a liquid recirculating reactor containing an embodiment of a distributor device.

Figure 9 is a schematic side view of another embodiment of a reactor containing an embodiment of the distributor device.

Figure 10 is a schematic side view of yet another embodiment of a liquid recirculating reactor containing a distributor device.

Figure 11 is a schematic side view of yet another embodiment of a reactor according to the present disclosure.

Figure 12 is a side elevational view of a portion of an embodiment of a downcomer.

Figure 13 is a top plan view of an embodiment of a downcomer.

Figure 14 is a perspective view of an embodiment of a modified duct for guiding a flow onto a degassing section of the downcomer.

DETAILED DESCRIPTION

In one embodiment, the invention relates to reactor equipment for use in heavy oil upgrade. "Heavy oil" refers to heavy and ultra-heavy crudes, including but not limited to resids, coals, bitumen, tar sands, etc. Heavy oil feedstock may be liquid, semi-solid, and / or solid. Examples of heavy oil feedstock that might be upgraded as described herein include but are not limited to Canada Tar sands,
vacuum resid from Brazilian Santos and Campos basins, Egyptian Gulf of Suez, Chad, Venezuelan Zulia, Malaysia, and Indonesia Sumatra. Other examples of heavy oil feedstock include bottom of the barrel and residuum left over from refinery processes, including "bottom of the barrel" and "residuum" (or "resid") atmospheric tower bottoms, which have a boiling point of at least 343°C. (650°F.), or vacuum tower bottoms, which have a boiling point of at least 524°C. (975°F.), or "resid pitch" and "vacuum residue" - which have a boiling point of 524°C. (975°F.) or greater. As used herein, the term "heavy oil" and "hydrocarbon" or "hydrocarbons" may be used interchangeably.

[035] The term "treatment," "treated," "upgrade," "upgrading" and "upgraded", when used in conjunction with a heavy oil feedstock, describes a process for processing a heavy oil feedstock in a reactor, resulting in a material or crude product which has a reduction in molecular weight (as compared to the heavy oil feedstock), a reduction in the boiling point range, a reduction in the concentration of asphaltenes, a reduction in the concentration of hydrocarbon free radicals, and/or a reduction in the quantity of impurities, such as sulfur, nitrogen, oxygen, halides, and metals.

[036] The slurry catalyst for use in the reactor system for upgrading heavy oil feedstock in one embodiment originates from a dispersed (bulk or unsupported) Group VIB metal sulfide catalyst promoted with at least one of: a Group VB metal such as V, Nb; a Group VIII metal such as Ni, Co; a Group VIIIB metal such as Fe; a Group IVB metal such as Ti; a Group HB metal such as Zn, and combinations thereof. Promoters are typically added to a catalyst formulation to improve selected properties of the catalyst or to modify the catalyst activity and/or selectivity.

[037] In one embodiment, the catalyst slurry has an average particle size of at least 1 micron in a hydrocarbon oil diluent. In another embodiment, the catalyst comprises slurry catalyst having an average particle size in the range of 1 - 20 microns. In a third embodiment, the catalyst comprises slurry catalyst an average particle size in the range of 2 - 10 microns. In one embodiment, the catalyst comprises a slurry catalyst having an average particle size ranging from colloidal (nanometer size) to about 1-2 microns. In another embodiment, the catalyst
comprises a slurry catalyst having molecules and/or extremely small particles that are colloidal in size (i.e., less than 100 nm, less than about 10 nm, less than about 5 nm, and less than about 1 nm).

[038] In one embodiment of the upgrade of heavy oil feedstock, the mixture or flow in the reactor typically comprises multi-phase components, i.e., all three phases, gas, liquid and solid. In the reactor, at least a portion of the heavy oil feedstock (higher boiling point hydrocarbons) is converted to lower boiling hydrocarbons, forming an upgraded product.

[039] In one embodiment, the flow comprises gases (e.g., hydrogen), volatile liquid (lighter hydrocarbon products or upgraded products) as well as non-volatile fractions, which comprises unconverted heavy oil feed, a small amount of heavier hydrocracked liquid products (synthetic or non-volatile upgraded products), the slurry catalyst and any entrained solids (asphaltenes, coke, etc.). Also in the reactor, a slurry feed comprising the heavy oil feedstock and a slurry catalyst can be admixed with a hydrogen rich gas, for example, at elevated pressure and temperature and hydroprocessed (for example, hydrocracked) for the removal of heteroatom contaminants, such as sulfur and nitrogen.

[040] In one embodiment of a reactor for use in the upgrade of heavy oil feedstock, the reactor comprises a distributor device for achieving a high degree of mixing of multi-phase components, including a gas phase. In one embodiment, the distributor device is for distributing multi-phase components, comprising a nozzle having a venturi outlet, a first pipe for feeding a gas phase into the nozzle, and a second pipe for feeding a slurry or liquid phase into the nozzle. A negative pressure created by the gas phase passing through the venturi outlet draws-in the slurry or liquid phase and discharges it through the venturi outlet, along with the gas phase, while mixing therewith. The distributor device thus serves to feed as well as mix the multi-phase components.

[041] Reference will be made to the figures to further illustrate embodiments of the invention.

[042] Figure 1 is a schematic view of an embodiment of a reactor 10 for use in heavy oil upgrade, which comprises a cylindrical casing 12 forming an inner
reaction chamber 14. A lower end piece 16 and a roof 18 are also provided to close
off the ends of the chamber. A feed of heavy hydrocarbons and catalyst slurry is
introduced into a lower portion of the chamber 14 through line 20, and hydrogen gas
is supplied via line 22. Alternatively, those components could be supplied in other
ways. The multi-phase mixture of hydrocarbons, slurry catalyst and hydrogen gas
can be distributed by a distributor 24 located near the bottom of the chamber.

[043] As the multi-phase mixture rises in the chamber 14, the hydrocarbons
react with the hydrogen and are hydrogenated. The hydrogenated hydrocarbons and
some unreacted gases are removed at upper portions of the chamber.

[044] Circulation of the multi-phase mixture within the chamber can be
induced by a pump 28 which produces a downward flow of the multi-phase mixture
through a vertical downcomer 30 disposed in the reactor. The downcomer 30 has
open upper and lower ends. The multi-phase mixture, comprising hydrocarbons,
liquefied slurry and hydrogen gas, is drawn into the open upper end of the
downcomer and discharged into the lower portion of the chamber.

[045] The upper portion of the downcomer 30 is configured to increase the
residence time of the mixture therein such that the downward velocity thereof is
slower than the natural ascension velocity of the gas bubbles, to promote escape of
the bubbles which would otherwise tend to impede the downward flow of the
mixture. Thus, an upper portion of the downcomer typically includes a frusto-
conical degassing section 34 which feeds downwardly into a cylindrical transport
section 36 of the downcomer whose diameter is less than a maximum diameter of
the degassing section 34.

[046] As the mixture descends toward the transport section 36, bubbles
escape upwardly and are drawn from the chamber and possibly reintroduced into a
lower portion of the chamber.

[047] The interior of the transport section 36 of the downcomer includes an
inner or central region 38 and an outer region 40 that is separated radially
(horizontally) from the inner region 38 by a vertical barrier 42 that is spaced from an
outer wall 43 of the transport section. The outer region can be in the form of a
continuous annular region as shown in Figure 3, but alternatively could be divided
into separate circumferentially adjacent regions. Openings 39 are provided in the barrier to communicate the outer and inner regions with one another.

[048] Mounted on a radially inner surface of the barrier 40 is a baffle structure 44 arranged to induce the mixture to travel downwardly in a helical path.

5 The baffle structure is arranged in a helicoidally path and can be perforated, in order to prevent solids from clogging along the baffle structure. The perforating of the baffle structure can be accomplished by providing holes in a continuous helical baffle (not shown) or by making the helical baffle structure discontinuous, i.e., comprised of spaced apart baffle sections 44a as depicted.

10 [049] As the multi-phase mixture travels downwardly in a helical direction through the transport section 36, the mixture is subjected to centrifugal force, causing the heavier (denser) components, such as a heavy (spent or used) catalyst, to be centrifugally urged radially outwardly away from the center of the transport section, whereupon the lighter (less dense) components, e.g., light (active) catalyst and gas bubbles, will migrate toward the center of the downcomer. This promotes the coalescence of small bubbles into larger bubbles having a greater tendency to rise in the inner region and escape from the downcomer.

15 [050] The baffle sections 44a do not extend all the way to the center of the downcomer, so a vertical passage is created for the upward flow of the gas bubbles, facilitating their escape, as well as enabling the lighter catalyst to flow downwardly.

20 [051] The heavier components being centrifugally urged outwardly will pass through the openings 39 in the barrier 42 and be collected in the outer region 40. Those heavier components, including hydrocarbons and catalyst slurry, move downwardly in the outer region and can be discharged from the reaction chamber through a discharge pipe 50 and sent, for example, to a regeneration station. To promote that discharge, the floor 52 of the outer region can be declined downwardly toward the discharge pipe as shown in Figure 4.

25 [052] Since the amount of denser components collected in the outer region becomes greater toward the lower portion of the downcomer, the width, i.e., radial dimension, of the outer region 40 can be made progressively greater in the downward direction in order to accommodate the increasingly received amounts of
denser components. In one embodiment, gas is removed from the mixture in the
downcomer to facilitate the descent of the mixture through the downcomer and any
subsequent recirculation thereof. Also, the slurry catalyst can be effectively
removed from mixture in the downcomer, and can be recirculated to a regeneration
station.

[053] Figure 5 illustrates another embodiment of a reactor 10, for use in the
upgrade of heavy oil feed by a slurry catalyst. The reactor 10 comprises a
cylindrical casing 12 closed off at its ends by a floor 14 and a roof 16. Disposed
near the bottom of the reactor's interior is a separation plate 18 which separates a
reaction chamber 20 of the interior from a collection chamber 22 disposed
therebeneath. Disposed adjacent the inner surface of the reaction chamber 20 is a
downcomer arrangement in the form of a plurality of circumferentially spaced
cylindrical downcomers 24 having upper inlets 26 disposed near the top of the
reaction chamber, and lower outlets 28 arranged to feed directly into the collection
chamber 22 through the separation plate 18. In one embodiment, in lieu of a
plurality of separate downcomers, the downcomer arrangement could comprise a
continuous annular channel arranged around the inner surface of the reaction
chamber coaxially with the center vertical axis of the reaction chamber.

[054] A feed pipe 30 is disposed near the bottom of the reaction chamber
for feeding in a multi-phase mixture, e.g., heavy hydrocarbons, a catalyst slurry, and
hydrogen gas. Alternatively, the gas could be introduced through a separate inlet.
The feed pipe 30 communicates with a distributor 32 disposed at the bottom of the
reaction chamber. The distributor can be of any suitable configuration, e.g.,
comprising a pair of branch lines 36 forming a U-shape and having nozzles directed
in any suitable upward, downward or angled directions, through which the multi-
phase mixture is discharged into the reaction chamber.

[055] In one embodiment, the reactor is configured so that the multi-phase
mixture travels upwardly in the reaction chamber in which the heavy hydrocarbons
react with the hydrogen. Hydrogenated hydrocarbons are removed from the upper
portion of the reaction chamber as is excess hydrogen gas. By locating the
downcomers near the wall of the reaction chamber, the center 20a of the reaction
chamber, where pressure is typically lowest and gases tend to accumulate, is left unencumbered (open), thus minimizing opposition to the upward travel of mixture. The rising gas tends not to migrate outwardly from the reactor's center to the wall thereof, so less gas becomes entrained in the downward flow through the downcomers. Less entrained gas means less resistance to downward flow.

[056] In one embodiment if the downcomer is instead disposed centrally, the mixture would flow upwardly along the wall of the reaction chamber and would be resisted by friction or surface tension at the wall. Instead, little if any of the mixture will flow upwardly along the wall, depending upon the number and spacing of the downcomers. By thus decreasing the resistance to the mixture's upward travel, a less powerful, and thus more efficient pump can be used to circulate the mixture. The pump efficiency is even further increased by the reduction of gas content in the mixture exiting the downcomers, enabling the pump to circulate a low-gas component.

[057] Hydrocarbons, catalyst slurry and residual hydrogen gas are conducted downwardly through the downcomers and into the collection chamber 22. Within the collection chamber the gases migrate upwardly from the liquefied slurry into a gas pocket 38 situated immediately beneath the separation plate 18. Recirculation of the liquefied slurry mixture from the collection chamber 22 back to the reaction chamber 20 is performed separately of the recirculation of the hydrogen gas as will be explained.

[058] A recirculation conduit 40 extends from a lower end of the collection chamber 22 and runs externally of the reactor before connecting to a distributor 42 located at a lower end of the reaction chamber. The distributor can be of any suitable construction. In an embodiment, the distributor comprises a conduit 44 extending between the branches 36 of the distributor 32 in the same plane therewith. The conduit 44 includes a plurality of downwardly projecting nozzles 46 for discharging the recirculated mixture into the reaction chamber. A pump 48, e.g., of the impeller type, is disposed in the recirculation line 40 for recirculating the mixture.
[059] It will be appreciated that the circulation of the multi-phase mixture through the reactor is achieved by the recirculation pump 48 in one embodiment. Additionally, if desired, an additional recirculation conduit 40a, pump 48a, and distributor 42a could be provided as shown.

[060] Extending from a valve 51 in the recirculation line 40 is a purge line 50 which periodically functions to remove the gas accumulated in the gas pocket 38 as will be explained. The purge line 50 extends to a gas discharge device 52 which comprises a tube 54 extending through the separation plate 18. The tube defines a passage 55 having a lower inlet end communicating with the gas pocket 38, and an upper outlet end having holes 56 disposed therein.

[061] As illustrated in Figure 6B, a cap 58 is mounted on the tube to form a channel communicating with the holes 56, the channel discharging above the separation plate, i.e., discharging into the lower portion of the reaction chamber.

[062] Figure 6B illustrates the valve in a closed state. As shown, disposed freely movably within the passage 55 is a valve e.g., a ball 60, which has a closed state in which it gravitates onto a seat 62 to block communication between the inlet and outlet of the passage 55.

[063] The purge line 50 extends into the inlet end of the passage 55 while leaving part of the inlet in communication with the gas pocket 38. As the mixture is being recycled through the recirculation line 40, the valve 51 is periodically actuated to cause some of that mixture to be diverted through the purge line, forcing the valve 60 off the seat, and enabling the liquid to flow into the inlet, thereby creating a negative pressure (venturi-action) which draws-in gas from the gas pocket 38. The gas mixes with the by-pass mixture as it is discharged into the reaction chamber.

[064] When the valve 51 is closed to terminate the flow of by-pass fluid, the valve ball 60 gravitates back into the seat 62, and a stem part 63 of the valve enters the purge line to block communication between the purge line and the gas pocket 38.

[065] With respect to a distribution device for a reactor in the upgrade of heavy oil feedstock, Figures 7A and 7B illustrate a distribution device 10, which includes first and second pipes 12, 14 which can be elongated in a curved direction,
for example, ring-shaped as shown. Attached between the pipes 12, 14, for example, at spaced locations around the inner circumferences thereof, are nozzles 16. Each nozzle communicates fluidly with both of the first and second pipes 12, 14 via respective passages and includes a nozzle passage 18 terminating in a venturi outlet 20 arranged so that pressurized gas fed from the first pipe 12 into the upper end of the nozzle passage passes through the venturi outlet whereby its speed is increased and pressure is reduced, thereby creating a negative pressure which draws-in the slurry or liquid phase from the second pipe 14. The result is a high degree of mixing and heat exchange between the components.

[066] In the ring-type hydrogen distributor device 10 illustrated in Figures 7A and 7B, the second ring-shaped pipe 14, having an inlet 2 for slurry or liquid phase, is disposed below the first ring-shaped pipe 12 having a hydrogen gas inlet 24. The outlets of the nozzles 16 are directed in a generally downward direction. Although the outlets of the nozzles could be directed vertically downwardly, some or all of the outlets can be directed at an angle relative to vertical, e.g., within a range up to ±45 degrees, in any desired pattern. Thus, for example, some nozzles could be directed at +45 degrees and others at -45 degrees as shown in Fig. 7C, or at angles therebetween.

[067] In one embodiment as illustrated, the device 10 is depicted as discharging the components in a downward direction. However, it could instead be inverted so as to discharge the components upward, i.e., vertically or at an angle to vertical.

[068] In one embodiment, the components delivered to the pipes 12, 14 can be recirculated from a reaction chamber via a pump, or can constitute fresh components. Each nozzle can have a diameter at its widest point of from about ½ inch to about 4 inches, for example, from about 1 inch to about 2 inches. The diameter at the nozzles' narrowest point can be from about ⅛ inch to about 2 inches, for example, from about ¼ inch to about 1 inch.

[069] The nozzle can produce a fluid spray pattern, wherein a ratio of a diameter of the fluid spray pattern to a diameter of a widest point of the nozzle is from about 1:1 to about 10:1, for example, from about 3:1 to about 7:1.
In one embodiment, the distributor device is disposed near the bottom of an up-flow reactor comprising a downcomer centered in the reactor, and a conventional distributor plate can be disposed above the device.

In yet another embodiment, a reactor can also comprise a distributor device that feeds the slurry or the liquid and the gas into the reactor near a top of the reactor. The reactor can further comprise a conduit at the top of the reactor that feeds the slurry or the liquid into the downcomer. The reactor can further comprise an internal or external recirculation pump for circulating the multi-phase mixture in the reactor.

Figure 8 is a schematic view of another embodiment of a reactor, e.g., a liquid recirculating reactor 30 which can be used for multi-component mixtures. The reactor contains an embodiment of a distributor device 10 located below an optional conventional distributor plate 29. That is, the distributor device could replace the distributor plate 29. The reactor 30 comprises a cylindrical casing 32 to which are attached an end piece 34 and a roof 36. Hydrogenated hydrocarbons and unreacted hydrogen can be withdrawn from locations near the top of the reactor, and liquid product can be separated from catalyst particles by either internal or external separation. Unreacted hydrogen withdrawn through the overhead product withdrawal line 38 can be recycled.

Material not removed can be recirculated through the downcomer 40, thereby keeping the catalyst concentration profile and temperature profile along the length of the reactor 30 as even as possible, thus maintaining the bubble flow regime. The downcomer 40 comprises at its upward end a cone 42 which permits gas bubbles to escape from the multi-phase mixture that enters the upper end of the downcomer 40. The downcomer 40 transports the degassed slurry to a lower point in the reactor 30. In an embodiment, sufficient hydrogen is introduced so that the superficial gas velocity through the reactor 30 is from about 2 to 6 cm/s. A recirculation pump 44 discharges material near the distributor device 10.

Figure 9 is a schematic view of another embodiment of a reactor 30a which contains a present distributor device 10 disposed below a distributor plate 29. As illustrated, the end piece 34a can be flat-bottomed, as opposed to round-
bottomed. As further illustrated, the downcomer 40a can: (1) terminate above the distributor device 10, as opposed to below the distributor device 10; (2) have a width at its bottom which is wider than its width at other points along its length; and/or (3) have outlets 46 in a horizontal direction in addition to a downward, vertical direction.

Figure 10 a schematic view of yet another embodiment of a reactor 30b containing a distributor device 10 disposed below a distributor plate 29. As illustrated, the liquid recirculating reactor 30b can optionally additionally comprise a feed pipe 50, for the addition of liquid/catalyst slurry to the downcomer, and/or optionally additionally comprise a conduit 52 adjacent the top of the reactor 30b for introducing a component to reduce slurry foaming in the reactor 30b. The second distributor device 52 can be the presently-disclosed ring-type distributor device 10 in which the hydrogen gas is replaced by a suitable liquid.

Figure 11 is a schematic view of another embodiment of a reactor 10 for upgrading heavy oil feedstock. The reactor 10 comprises a cylindrical casing 12 forming an inner reaction chamber 14. A lower end piece 16 and a roof 18 are also provided to close off the ends of the chamber. A feed of heavy hydrocarbons and liquefied catalyst slurry is introduced into a lower portion of the chamber 14 through line 20, and hydrogen gas is supplied via line 22. Those components can be introduced into the reaction chamber by way of a distributor ring 23 disposed in a lower portion of the reaction chamber and having discharge nozzles aimed in any desired direction(s). The thus-introduced multi-phase mixture of hydrocarbons, liquefied slurry and hydrogen gas can be distributed by a distributor plate 24 located above the distributor ring.

As the multi-phase mixture rises in the chamber 14, the hydrocarbons react with the hydrogen and are hydrogenated. The hydrogenated hydrocarbons and some unreacted gases are removed at upper portions of the chamber.

Circulation of the multi-phase mixture within the chamber can be induced by a pump 28 which produces a downward flow of the multi-phase mixture through a vertical downcomer 30 disposed in the reactor. The downcomer 30 has open upper and lower ends. The multi-phase mixture, comprising hydrocarbons,
liquefied slurry and hydrogen gas, is drawn into the open upper end of the
downcomer and discharged into the lower portion of the chamber.

[079] The upper portion of the downcomer 30 is configured to increase the
residence time of the mixture therein such that the downward velocity thereof is
slower than the natural ascension velocity of the gas bubbles, to promote escape of
the bubbles which would otherwise tend to impede the downward flow of the
mixture. Thus, an upper portion of the downcomer typically includes a degassing
section 34 which feeds into a cylindrical transport section 36 of the downcomer
whose diameter is less than a maximum diameter of the degassing section 34.

[080] Conventionally, the multi-phase mixture would be expected to flow
into the degassing section over the upper edge thereof. As the mixture descends
generally linearly toward the transport section 36, bubbles would escape upwardly
and be drawn from the chamber through a line 40 and possibly reintroduced into a
lower portion of the chamber.

[081] The escape of bubbles is promoted by further increasing the residence
time of the flowing mixture within the degassing section 34 and by accomplishing
that in a way which induces smaller bubbles to coalesce and form larger bubbles
having an increased natural ascension velocity.

[082] That is achieved, for example, by configuring the degassing section
as a pan 33 having a frusto-conical upper surface 39, and conducting the multi-phase
mixture along that surface in a downward helical flow which produces centrifugal
forces acting on the surface so as to centrifugally urge heavier (more dense)
components of the mixture outwardly away from a center axis A of the surface,
whereby lighter (less dense) components, such as the bubbles, are caused to migrate
inwardly toward the center axis A.

[083] To produce the helical flow, the pan 33 is provided with inlets 40 that
introduce the mixture into the degassing section in a tangential direction.
Preferably, the diameter of the upper edge of the pan 33 is equal to or almost equal
to the diameter of the reaction chamber to prevent upward leakage of the slurry past
the pan and the inlets 40. Each inlet 40 includes a through-hole 42 and a duct 44
surrounding the through-hole 42. The through-hole passes completely through the
pan from the underside 46 to the upper surface 39 thereof. The duct 44 is attached to the upper surface and forms a guide passage 50 that constrains the mixture to flow in a tangential direction, i.e., a direction perpendicular to a radial line from the center axis A. This results in a downward helical flow of the mixture toward the transport section 36, which helical flow constitutes a longer overall path of travel as compared to a conventional downward linear path of travel. Also, the centrifugal force which urges the denser components outwardly and allows the less dense components, like bubbles, to migrate inwardly, results in smaller bubbles accumulating near a central vortex region of the flowing mixture where they can coalesce into fewer, larger bubbles that exhibit a greater tendency to rise. As a result, there occurs an improved gas separation.

[084] The duct 44 can be curved as shown in Figure 13, or straight as shown in Figure 14. Also, the duct can define a linear passage as shown, or it could be shaped as an elbow having a vertical inlet portion and a horizontal outlet portion. A desired ratio of duct length to duct cross-section is in the range of 1 to 10. In one embodiment, from 3 to 5.

[085] As illustrated in Figure 12, the upper surface 39 of the pan 33 can be provided with baffles 60 downstream of the inlets 40. The baffles are spaced apart along the upper surface 39, for example, in a generally helical pattern, to help constrain the mixture to flow in a helical travel path, and delay the inward collapsing of the flow path to the center axis. Instead, the mixture will flow along the longer helical path at a slower speed, thereby maximizing the residence time of the mixture in the degassing section 34, and thus maximizing the removal of gas bubbles. The number of baffles, as well as their size, shape, location and orientation is not critical as long as a suitable increase in residence time for the mixture is achieved.

[086] It will be appreciated that, in accordance with the present disclosure, there is achieved a greater separation and escape of gas bubbles from the multi-phase mixture, thereby promoting a downward flow of the mixture in the downcomer.
[087] The gas removed via line 40 and/or the slurry exiting the bottom of the downcomer can be recirculated back into the reaction chamber if desired, e.g., through the distributor ring 23 or in another suitable manner.

[088] Many modifications of the exemplary embodiments disclosed herein will readily occur to those of skill in the art. Accordingly, the present disclosure is to be construed as including all structure and methods that fall within the scope of the appended claims.
WHAT IS CLAIMED IS:

1. A reactor for the upgrade of heavy oil feedstock using a slurry catalyst, the reactor comprising:
   a reaction chamber having a substantially unencumbered center portion through which a multi-phase mixture is conducted upwardly;
   a downcomer arrangement disposed laterally outwardly of the center portion and adjacent to an inner surface of the reaction chamber; and
   an external pump communicating with a lower portion of the reaction chamber for circulating components of the mixture downward from an upper end of the downcomer arrangement to a lower end thereof; wherein the multi-phase mixture comprises gases, volatile liquid including upgraded products and non-volatile fractions comprising the slurry catalyst.

2. The reactor of claim 1, further including a collection chamber disposed below the reaction chamber into which the components exiting the downcomer arrangement are introduced and where the gas is separated from the remainder of the components.

3. The reactor according to claim 2, wherein a gas-containing pocket of the collection chamber communicates with the reaction chamber independently of the pump, and the pump is connected to recycle the remaining components from the collection chamber to the reaction chamber.

4. A reactor for the upgrade of heavy oil feedstock using a slurry catalyst, the reactor comprising:
   a reaction chamber in which a multi-phase mixture is conducted;
   a collection chamber, separated from the reaction chamber, in which some of the mixture is collected from the reaction chamber, wherein gas from the mixture migrates upwardly to form a gas pocket in the collection chamber; and
a recycling mechanism interconnecting the collection chamber and the reaction chamber, and comprising:

a recycling conduit extending from a lower end of the collection chamber and feeding into the reaction chamber,

a pump for circulating the mixture through the recycling conduit from the collection chamber to the reaction chamber,

a discharge device forming a passage having an inlet communicating with the gas pocket, and an outlet communicating with the reaction chamber, and

a purge line for by-passing some of the mixture from the recycling conduit, under pressure from the pump, through the passage in a manner creating a negative pressure for drawing-in gas from the gas pocket, wherein the gas and the by-passing mixture are discharged through the outlet and into the reaction chamber;

wherein the multi-phase mixture comprises gases, volatile liquid and non-volatile fractions comprising the slurry catalyst.

5. The reactor according to claim 4, wherein the recycling mechanism further includes a valve movable from a closed state to an open state for opening the passage to couple the inlet with the outlet, wherein the purge line is arranged to direct the by-passing mixture against the valve to move the valve from a closed state to the open state.

6. The reactor according to any of claims 4 - 5, wherein the reaction chamber is separated from the collection chamber by a separation plate extending across an interior of the reaction chamber, the passage of the discharge device extending through the separation plate.

7. The reactor according to any of claims 4 - 6, wherein the reactor is an upflow reactor and includes a downcomer arranged for conducting mixture from an upper end thereof to a lower end thereof which communicates with the collection chamber through the separation plate.
8. The reactor according to any of claims 4 - 7, wherein the recycling conduit feeds into the reaction chamber through a distributor having multiple nozzles.

9. A reactor for the upgrade of heavy oil feedstock using a slurry catalyst, the reactor comprising a downcomer for downwardly conducting a multi-phase mixture, the downcomer comprising an interior in which is disposed a baffle structure arranged to induce the mixture to flow in a downward generally helical path such that denser components of the mixture are centrifugally urged outwardly away from a center of the downcomer and less dense components migrate toward the center; wherein the multi-phase mixture comprises gases, volatile liquid and non-volatile fractions comprising the slurry catalyst.

10. The reactor for the upgrade of heavy oil feedstock according to claim 9, wherein the baffle structure in the downcomer is perforated.

11. A reactor for the upgrade of heavy oil feedstock using a slurry catalyst, the reactor comprising a downcomer for downwardly conducting a multi-phase mixture, the downcomer comprising:

   a transport section having an interior comprised of inner and outer regions separated horizontally by a generally vertical barrier;

   a baffle structure disposed on an inner surface of the barrier and arranged to induce the mixture to flow in a downward generally helical path such that denser components of the mixture are centrifugally urged outwardly away from a center of the downcomer and less dense components migrate toward the center;

   wherein the barrier includes openings enabling the denser components to travel from the inner region to the outer region to be collected herein; and

   wherein the multi-phase mixture comprises gases, volatile liquid and non-volatile fractions comprising the slurry catalyst.

12. The reactor for the upgrade of heavy oil feedstock according to claim 11, wherein the outer region comprises an annular region surrounding the inner region.
13. The reactor for the upgrade of heavy oil feedstock according to any of claims 11-12, wherein the downcomer further including a discharge passage for conducting the collected denser components from the outer region.

14. A reactor for the upgrade of heavy oil feedstock using a slurry catalyst, the reactor comprising a device for distributing a multi-phase mixture processed in the reactor, the multi-phase mixture comprises a mixture of gases, volatile liquid and non-volatile fractions comprising the slurry catalyst, the distributing device comprising:

- a first pipe adapted for conducting a gas phase;
- a second pipe adapted for conducting the slurry catalyst or the volatile liquid;

and

at least a nozzle including passages communicating the first pipe and the second pipe,

wherein the nozzle a venturi outlet of the nozzle such that pressurized gas phase from the first pipe passing through the venturi outlet creates a negative pressure for drawing-in the slurry catalyst or the volatile liquid,

and wherein the slurry catalyst or the volatile liquid is mixed with the gas phase in the venturi outlet.

15. The reactor for the upgrade of heavy oil feedstock according to claim 14, wherein at least one of the first and second pipes is elongated and includes a plurality of respective first and second discharge ports, there being a nozzle associated with each pair of first and second discharge ports.

16. The reactor for the upgrade of heavy oil feedstock according to claim 14, wherein each of the first and second pipes is ring-shaped, and respective center axes of the ring-shaped pipes are substantially coincident with each other, and there is a plurality of the nozzles arranged in a ring-shaped pattern between the first and second pipes.
17. The reactor for the upgrade of heavy oil feedstock according to any of claims 14 - 16, wherein the venturi outlet is arranged to admit the slurry or the liquid phase in surrounding relationship to the gas phase.

18. The reactor for the upgrade of heavy oil feedstock according to any of claims 14 - 17, wherein there is a plurality of the nozzle and wherein some of the venturi outlets being directed at different respective angles relative to a vertical axis.

19. The reactor for the upgrade of heavy oil feedstock according to any of claims 14 - 18, wherein at least a nozzle produces a fluid spray pattern, and wherein a ratio of a diameter of the fluid spray pattern to a diameter of a widest point of the nozzle passage being from about 3:1 to about 7:1.

20. The reactor for the upgrade of heavy oil feedstock according to any of claims 14 - 19, further including a downcomer disposed in the chamber for recirculating the multi-phase mixture.

21. The reactor for the upgrade of heavy oil feedstock according to any of claims 14 - 20, wherein the distributor device is located nearer to a bottom of the reactor than to a top thereof.

22. The reactor for the upgrade of heavy oil feedstock according to any of claims 14 - 21, further comprising a conduit arranged adjacent a top of the reactor for feeding the slurry catalyst or the volatile liquid downwardly into a downcomer.

23. A reactor for the upgrade of heavy oil feedstock using a slurry catalyst, the reactor comprising a downcomer for conducting a downward flow of a multi-phase mixture including gas bubbles, comprising:
a transport section; and
a degassing section disposed at an upper end of the transport section, the
degassing section including a pan having a generally frusto-conical upper surface,
the pan having a plurality of circumferentially spaced inlets for admitting a flow of
a multi-phase mixture, each inlet including a duct oriented to introduce the inflowing
mixture onto the upper surface generally tangentially, whereupon the mixture flows
in a downward helical direction along the upper surface, causing denser components
to be urged outwardly away from a center axis of the surface, and less dense
components to migrate inwardly toward the center axis where smaller gas bubbles
coalesce into larger bubbles;
wherein the multi-phase mixture comprises gases, volatile liquid and non-
volatile fractions comprising the slurry catalyst.

24. The reactor for the upgrade of heavy oil feedstock using a slurry catalyst,
according to claim 23, wherein each inlet of the downcomer also includes a through-
hole extending through the pan; a respective duct arranged around the through-hole.

25. The reactor for the upgrade of heavy oil feedstock using a slurry catalyst,
according to claim 23, wherein the downcomer further comprises at least one baffle
disposed on the upper surface of the pan downstream of the inlet and arranged to
guide the flow of the multi-phase mixture in a generally helical direction.

26. The reactor for the upgrade of heavy oil feedstock using a slurry catalyst,
according to claim 23, wherein the downcomer comprises a plurality of baffles
arranged in a generally helical pattern.

27. The reactor for the upgrade of heavy oil feedstock using a slurry catalyst,
according to any of claims 23 - 26, wherein the degassing section and the transport
section are coaxially arranged.
28. A reactor for the upgrade of heavy oil feedstock using a slurry catalyst, the reactor comprising:
   a casing forming a reaction chamber for conducting an upwardly traveling a multi-phase mixture; and
   a vertical downcomer disposed in the casing for recirculating the multi-phase mass, the downcomer including a transport section, and a degassing section disposed at an upper end of the transport section,
   wherein the degassing section includes a pan having a generally frusto-conical upper surface on which are disposed a plurality of circumferentially spaced inlets for admitting the multi-phase mixture, each inlet including a duct oriented to introduce the inflowing mixture onto the upper surface generally tangentially, whereupon the mixture flows in a generally helical downward direction along the upper surface, causing denser components to be centrifugally urged outwardly away from a center axis of the pan and less dense components to migrate inwardly toward the center axis where small bubbles coalesce into large bubbles;
   wherein the multi-phase mixture comprises gases, volatile liquid and non-volatile fractions comprising the slurry catalyst.

29. The reactor according to claim 28, wherein each inlet includes a through-hole extending through the pan; the ducts arranged around respective through-holes.

30. The reactor according to claim 28, further including at least one baffle disposed on the upper surface of the pan and arranged to guide the flow of multi-phase mixture in the generally helical direction.

31. The reactor according to claim 28, wherein the degassing section and the transportation section are coaxial with a center axis of the reaction chamber, an outer diameter of an upper edge of the pan being substantially equal to a diameter of an inner surface of the reaction chamber to resist leakage of multi-phase mixture past the upper edge of the pan.
32. The reactor according to any of claims 28-31, further including a pump for circulating the multi-phase mixture within the reactor.

33. The reactor according to any of claims 28-32, further including a distributor ring disposed within the reaction chamber adjacent a lower end thereof for introducing the gas and the catalyst slurry.

34. The reactor according to any of claims 28-33, further including a distributor plate extending across a lower portion of the reaction chamber above the distributor ring.

35. A method of distributing a multi-phase mixture in a reaction chamber of a reactor for use in the upgrade of heavy oil feedstock employing a slurry catalyst, comprising:

   communicating the slurry catalyst, the heavy oil feedstock, and a source of pressurized gas phase with a nozzle disposed in the chamber, forming a multi-phase mixture, with the multi-phase mixture comprising gases, volatile liquid and non-volatile fractions comprising the slurry catalyst.

   conducting the pressurized gas phase through venturi outlets of the nozzle to create a negative pressure which draws the multi-phase mixture into the venturi outlet; and

   discharging the multi-phase mixture from the venturi outlet and into the chamber.

36. A method of separating components of a multi-phase mixture in a downcomer of a reactor for use in the upgrade of heavy oil feedstock employing a slurry catalyst, wherein the multi-phase mixture comprises gases, volatile liquid and non-volatile fractions comprising the slurry catalyst, the method comprising:

   feeding the multi-phase mixture into an interior of the downcomer; and
inducing the multi-phase mixture to flow in a downward, generally helical direction, wherein denser components including the slurry catalyst are centrifugally urged away from a center of the interior, and less dense components migrate toward the center.

37. A method of separating components of a multi-phase mixture in a downcomer of a reactor for use in the upgrade of heavy oil feedstock employing a slurry catalyst, wherein the multi-phase mixture comprises gases, volatile liquid and non-volatile fractions comprising the slurry catalyst, comprising:

feeding the multi-phase mixture into an inner region of the downcomer's interior, which inner region is separated by a barrier from an outer region of the downcomer's interior,

inducing the mixture to flow in a downward generally helical direction in the inner region, wherein denser components of the multi-phase mixture including the slurry catalyst are centrifugally urged away from a center of the downcomer, and less dense components migrate toward the center, and

admitting the centrifugally urged denser components into the outer region through openings formed in the barrier.

38. A process for the upgrade of heavy oil feedstock in a reactor using a slurry catalyst, the process comprising:

providing a mixture of components including the heavy oil feedstock, the slurry catalyst, and hydrogen gas in a lower portion of a reaction chamber of the reactor;

conducting the mixture upwardly in a substantially unencumbered center section of the reaction chamber, and then

conducting at least the heavy oil feedstock and catalyst components of the mixture by pumping those components downwardly through a downcomer arrangement disposed laterally of the center and near an inner surface of the reaction chamber.
39. A process for recycling within a reactor a multi-phase mixture, with the multi-phase mixture comprising gases, volatile liquid and non-volatile fractions comprising a slurry catalyst, the process comprising:

   collecting some of the multi-phase mixture in a collection chamber of the reactor disposed below, and isolated from, a reaction chamber of the reactor, wherein gas migrates upwardly from the mixture to a gas pocket in the collection chamber;

   recycling degasified mixture, under pressure of a pump from the collection chamber, through an exterior recycling conduit from the collection chamber to the reaction chamber; and

   opening a passage extending between the gas pocket and the reaction chamber, and circulating some of the pressurized mixture from the recycling conduit to the passage in a manner creating a negative pressure in the passage for drawing-in gas from the gas pocket, wherein the pressurized mixture traveling through the passage combines with the drawn-in gas and is discharged into the reaction chamber.

40. The process according to claim 39, wherein the recycled mixture is fed into the reaction chamber through nozzles of a distributor.