(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
4 December 2014 (04.12.2014)

WIPO | PCT

(10) International Publication Number
WO 2014/193612 A1

(51) International Patent Classification:
B01J 8/18 (2006.01) *B01J 19/24* (2006.01)
B01J 8/08 (2006.01)

(21) International Application Number:
PCT/US2014/036903

(22) International Filing Date:
6 May 2014 (06.05.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
13/907,232 31 May 2013 (31.05.2013) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) Title: EXTENDED CONTACT TIME RISER

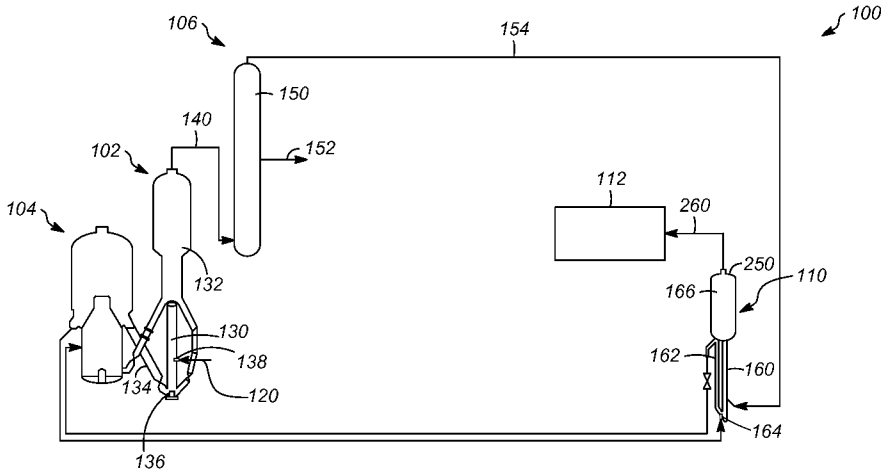

FIG. 1

(57) Abstract: A riser includes a housing in communication with a entry conduit and an exit conduit. The housing is defined by a holdup chamber having a volume of between 1133 liters and 45307 liters. The riser is designed to receive a hydrocarbon feed and a catalyst. An apparatus for fluid catalytic cracking includes a riser in fluid communication with a reactor vessel. A hydrocarbon feed stream and a catalyst travel through a first section of the riser at a first velocity of between 1.5 m/sec to 10 m/sec and through a second section of the riser at a second velocity of more than 15 m/sec. A process for fluid catalytic cracking uses a riser with a hol - dup chamber. A hydrocarbon feed and a catalyst decrease in velocity in the holdup chamber to between 1.5 m/sec and 10 m/sec.

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EXTENDED CONTACT TIME RISER

STATEMENT OF PRIORITY

[0001] This application claims priority to U.S. Application No. 13/907,232 which was filed May 31, 2013, the contents of which are hereby incorporated by reference in its entirety.

BACKGROUND OF THE DISCLOSURE

1. Field of the Disclosure

[0002] This invention relates to a riser for use in a fluid catalytic cracking system, and more particularly to a riser having a design that increases the conversion rate of feedstock flowing therethrough.

2. Description of the Background of the Disclosure

[0003] Fluid catalytic cracking (FCC) is a catalytic hydrocarbon conversion process accomplished by contacting heavier hydrocarbons in a fluidized reaction zone with a catalytic particulate material. The reaction in catalytic cracking, as opposed to hydrocracking, is carried out in the absence of substantial added hydrogen or the consumption of hydrogen. As the cracking reaction proceeds, substantial amounts of highly carbonaceous material referred to as coke are deposited on the catalyst to provide coked or spent catalyst. Vaporous lighter products are separated from spent catalyst in a reactor vessel. Spent catalyst may be subjected to stripping over an inert gas such as steam to strip entrained hydrocarbonaceous gases from the spent catalyst. A high temperature regeneration with oxygen within a regeneration zone operation burns coke from the spent catalyst that may have been stripped. Various products may be produced from such a process, including a naphtha product and/or a light product such as propylene and/or ethylene.

[0004] The basic components of the FCC process include an internal or external riser, a reactor vessel in which spent catalyst is disengaged from product vapors, a regenerator, and a catalyst stripper. In the riser, the hydrocarbon feed contacts the catalyst and is cracked into a product stream containing lighter hydrocarbons. A gas stream is typically used to accelerate catalyst in a first section of the riser before introduction of the feed. Regenerated catalyst and the hydrocarbon feed are transported upwardly in the riser by the expansion of the gases that

result from the vaporization of the hydrocarbons, and other fluidizing mediums, upon contact with the hot catalyst.

[0005] In such processes, a single reactor vessel or a dual reactor vessel can be utilized. Although additional capital costs may be incurred by using a dual reactor vessel, one of the reactors can be operated to tailor conditions for maximizing products, such as light olefins including propylene and/or ethylene. It can often be advantageous to maximize yield of a product in one of the reactors. Additionally, there may be a desire to maximize the production of a product from one reactor that can be recycled back to the other reactor to produce a desired product, such as propylene. Normally if two reactors are used, a single product recovery system is utilized for product separation. Separate product recovery systems have also been proposed. Maximizing synergies between two reactor systems is greatly desired.

[0006] The conversion efficiency of feedstock as it travels through a riser is dependent upon various factor including, for example, riser temperature, pressure, catalyst/oil ratio, catalyst properties, zeolite concentration in the circulating catalyst, and various other factors including the residence time in the reactor. One particularly difficult obstacle is the conversion of the feedstock into propylene, which is limited by equilibrium.

[0007] Commercially there is a demand for FCC technology capable of producing high propylene yields from conventional feedstocks. While it is possible to affect the propylene yield in a conventional FCC unit by adjusting the process conditions and the catalyst composition, the extent of propylene production is equilibrium-limited. One means of increasing the propylene yield is to decrease the reactor pressure to decrease olefin partial pressure. However, reducing the reactor pressure leads to a large increase in capital cost and an even larger increase in the utility costs. An alternative solution is feeding light naphtha to the primary reactor riser or to a second reactor riser from a conventional separation section having a main column and gas recovery unit. Both of these options result in an increase in capital costs, but the process economics are much more favorable than simply reducing the reactor pressure. If one recycles light naphtha to a conventional reactor riser to increase propylene yield, the capital costs increase slightly with essentially no increase in utility costs. Propylene yield can be increased to still a greater extent more economically by increasing the residence time of the feedstock in the riser. One such way that the residence time may be increased is through the use of a specially designed riser according to the disclosure herein.

SUMMARY OF THE INVENTION

[0008] According to one aspect of the invention, a riser comprises a housing in communication with a entry conduit and an exit conduit. The housing is defined by a holdup chamber having a volume of between 1133 liters (40 ft^3) to 45307 liters (1600 ft^3), and is designed to receive a hydrocarbon feed and a catalyst. The width dimension of the holdup chamber can be greater than the width dimension of at least one of the entry conduit or exit conduits. The width dimension of the holdup chamber can be greater than the width dimension of both of the entry conduit and exit conduits. The holdup chamber can include an angled lower surface and an angled upper surface, wherein the angled lower surface and the angled upper surface are each characterized by an angle of between 20 degrees to 60 degrees. The holdup chamber can disrupt the flow of the catalyst along an interior surface thereof.

[0009] According to another aspect of the invention, an apparatus for fluid catalytic cracking includes a riser in communication with a reactor vessel designed to receive a feed stream and a catalyst. The feed stream and the catalyst travel through a first section of the riser at a first velocity of between 1.524 m/sec (5 ft/sec) to 9.144 m/sec (30 ft/sec) and through a second section of the riser at a second velocity of more than 15.24 m/sec (50 ft/sec). The feedstream can comprise C_4 to C_7 olefins. The catalyst can be a zeolite. The feed stream may react with the catalyst to form polypropylene. The feed stream can comprise a previously cracked feed. The riser can be defined by a holdup chamber. The holdup chamber can include a protruding section that increases the residence time of the feed stream and the catalyst therein. The holdup chamber can include at least one angled surface disposed adjacent an upper or lower surface. Both an upper and a lower surface of the holdup chamber can be angled. The volume dimension of the holdup chamber can be 1133 liters (40 ft^3) to 45307 liters (1600 ft^3). The first section of the riser can be the holdup chamber.

[0010] According to yet another aspect of the invention, a process for fluid catalytic cracking uses a riser including a housing in fluid communication with an entry conduit and an exit conduit, wherein the housing is defined by a holdup chamber. A hydrocarbon feed and a catalyst are directed through the entry conduit, the housing, and the exit conduit of the riser. A velocity of the hydrocarbon feed and the catalyst decreases in the holdup chamber such that the velocity of the hydrocarbon feed and the catalyst is between 1.5 m/sec and 10 m/sec as the feed and catalyst are traveling through the holdup chamber. The velocity of the

hydrocarbon feed and the catalyst may be less than 4.5m/sec as the feed and catalyst enter the entry conduit. A residence time of the hydrocarbon feed and the catalyst in the holdup chamber can be between 0.5 to 5.0 seconds.

[0011] These and other features, aspects, and advantages of the present invention will become better understood upon consideration of the following detailed description, drawings, and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 is a schematic view of one embodiment of a fluid catalytic cracking process that utilizes a riser;

[0013] FIG. 2 is an isometric view of one embodiment of a riser for use in the process of FIG. 1;

[0014] FIG. 3 is an isometric view of another embodiment of a riser for use in the process of FIG. 1;

[0015] FIG. 4 is a side elevational view of the riser of FIG. 4; and

[0016] FIG. 5 is a partial cross-sectional view of the riser of FIG. 4 taken generally along the lines 5-5 of FIG. 3.

DETAILED DESCRIPTION OF THE DRAWINGS

[0017] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having" and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Unless specified or limited otherwise, the terms "mounted," "connected," "supported," and "coupled" and variations thereof are used broadly and encompass both direct and indirect

mountings, connections, supports, and couplings. Further, "connected" and "coupled" are not restricted to physical or mechanical connections or couplings.

[0018] The following discussion is presented to enable a person skilled in the art to make and use embodiments of the invention. Various modifications to the illustrated embodiments will be readily apparent to those skilled in the art, and the generic principles herein can be applied to other embodiments and applications without departing from embodiments of the invention. Thus, embodiments of the invention are not intended to be limited to embodiments shown, but are to be accorded the widest scope consistent with the principles and features disclosed herein. The following detailed description is to be read with reference to the figures, in which like elements in different figures have like reference numerals. The figures, which are not necessarily to scale, depict selected embodiments and are not intended to limit the scope of embodiments of the invention. Skilled artisans will recognize the examples provided herein have many useful alternatives and fall within the scope of embodiments of the invention.

[0019] This invention relates generally to a riser for use in an FCC process, and to the improved FCC process. The process and apparatus of this invention can be used to modify the operation and arrangement of existing FCC units or in the design of newly constructed FCC units.

[0020] The present invention is an apparatus and process that may be described with reference to numerous components generally depicted in FIG. 1. In particular, an FCC process 100 includes a first catalytic reactor 102 that is operatively connected to a regenerator vessel 104 and a first product fractionation section 106. The first product fractionation section 106 is in communication with a second catalytic reactor 110 and a second product recovery section 112. A gas recovery section (not shown) is optionally provided that is in communication with the first product fractionation section 106. Many configurations of the present invention are possible, but specific embodiments are presented herein by way of example. All other possible embodiments for carrying out the present invention are considered within the scope of the present invention. For example, if the first and second reactors 102, 110 are not FCC reactors, the regenerator vessel 104 may be optional. One particularly useful FCC process 100 and associated components that utilize a riser discussed

herein is described in U.S. Patent Application Publication No. 2011/0110825 which is incorporated herein by reference in its entirety.

[0021] A conventional FCC feedstock and higher boiling hydrocarbon feedstock are a suitable first feed 120 to the first reactor 102. The most common of such conventional feedstocks is a "vacuum gas oil" (VGO), which is typically a hydrocarbon material having a boiling range of from 343°C to 552°C (650°F to 1025°F) prepared by vacuum fractionation of atmospheric residue. Such a fraction is generally low in coke precursors and heavy metal contamination that can serve to contaminate catalyst. Heavy hydrocarbon feedstocks to which this invention may be applied include heavy bottoms from crude oil, heavy bitumen crude oil, shale oil, tar sand extract, deasphalted residue, products from coal liquefaction, atmospheric and vacuum reduced crudes. Heavy feedstocks for this invention also include mixtures of the above hydrocarbons and the foregoing list is not comprehensive. Moreover, additional amounts of feed may also be introduced downstream of the initial feed point.

[0022] The first reactor 102 may be a catalytic or an FCC reactor that includes a first reactor riser 130 in communication with a first reactor vessel 132. A regenerator catalyst standpipe 134 is in upstream communication with the first reactor 102. The regenerator catalyst standpipe 134 delivers regenerated catalyst from the regenerator vessel 104 at a rate regulated by a control valve to the first reactor 102 through a regenerated catalyst inlet. A fluidization medium such as steam from a distributor 136 urges a stream of regenerated catalyst upwardly through the first reactor 102. At least one feed distributor 138 in upstream communication with the first reactor 100 injects the first feed 120, preferably with an inert atomizing gas such as steam, across the flowing stream of catalyst particles to distribute hydrocarbon feed to the first reactor 102. Upon contacting the first feed 120 with catalyst in the first reactor 102, the heavier first feed 120 cracks to produce lighter gaseous first cracked products while conversion coke and contaminant coke precursors are deposited on the catalyst particles to produce spent catalyst.

[0023] The catalyst may be a single catalyst or a mixture of different catalysts. Usually, the catalyst includes two components or catalysts, namely a first component or catalyst, and a second component or catalyst. A useful catalyst mixture is disclosed in, for example, U.S. Patent No. 7,312,370, incorporated by reference herein in its entirety. Generally, the first component may include any of the well-known catalysts that are used in the art of FCC, such

as an active amorphous clay-type catalyst and/or a high activity, crystalline molecular sieve. Zeolites may be used as molecular sieves in FCC processes. Preferably, the first component includes a large pore zeolite, such as a Y-type zeolite, an active alumina material, a binder material, including either silica or alumina, and an inert filler such as kaolin.

[0024] Typically, the zeolitic molecular sieves appropriate for the first component have a large average pore size. Usually, molecular sieves with a large pore size have pores with openings of greater than 0.7 nanometers in effective diameter defined by greater than 10, and typically 12, member rings. Suitable large pore zeolite components may include synthetic zeolites such as X and Y zeolites, mordenite and faujasite. A portion of the first component, such as the zeolite, can have any suitable amount of a rare earth metal or rare earth metal oxide.

[0025] The second component may include a medium or smaller pore zeolite catalyst, such as a MFI zeolite, as exemplified by at least one of ZSM-5, ZSM-11, ZSM-12, ZSM-23, ZSM-35, ZSM-38, ZSM-48, and other similar materials. Other suitable medium or smaller pore zeolites include ferrierite, and erionite. Preferably, the second component has the medium or smaller pore zeolite dispersed on a matrix including a binder material such as silica or alumina and an inert filler material such as kaolin. The second component may also include some other active material such as Beta zeolite. These compositions may have a crystalline zeolite content of 10 to 50 wt-% or more, and a matrix material content of 50 to 90 wt-%. Components containing 40 wt-% crystalline zeolite material are preferred, and those with greater crystalline zeolite content may be used. Generally, medium and smaller pore zeolites are characterized by having an effective pore opening diameter of less than or equal to 0.7 nm and rings of 10 or fewer members. Preferably, the second catalyst component is an MFI zeolite having a silicon-to-aluminum ratio greater than 15, preferably greater than 75. In one exemplary embodiment, the silicon-to-aluminum ratio can be 15:1 to 35:1.

[0026] The total catalyst mixture may contain 1 to 25 wt-% of the second component, including a medium to small pore crystalline zeolite with greater than or equal to 7 wt-% of the second component being preferred. When the second component contains 40 wt-% crystalline zeolite with the balance being a binder material, an inert filler, such as kaolin, and optionally an active alumina component, the catalyst mixture may contain 0.4 to 10 wt-% of the medium to small pore crystalline zeolite with a preferred content of at least 2.8 wt-%. The

first component may comprise the balance of the catalyst composition. The high concentration of the medium or smaller pore zeolite as the second component of the catalyst mixture can improve selectivity to light olefins. In one exemplary embodiment, the second component can be a ZSM-5 zeolite and the catalyst mixture can include 0.4 to 10 wt-% ZSM-5 zeolite excluding any other components, such as binder and/or filler.

[0027] The resulting mixture of gaseous product hydrocarbons and spent catalyst continues upwardly through the first reactor 102 and are received in the first reactor vessel 132 in which the spent catalyst and gaseous product are separated. The mixture of gas and catalyst are discharged from a top of the first reactor 102 through one or more outlet ports (not shown) into a disengaging vessel (not shown in detail) that effects partial separation of gases from the catalyst. The hydrocarbon vapors, including stripped hydrocarbons, stripping media and entrained catalyst are sent to the first reactor vessel 132 to separate spent catalyst from the hydrocarbon gaseous product stream.

[0028] The separated hydrocarbon gaseous streams from the first reactor vessel 132 are sent via a product line 140 via into the first product fractionation section 106 for product recovery.

[0029] Meanwhile, catalyst is discharged into a lower bed in the first reactor vessel 132. The catalyst with adsorbed or entrained hydrocarbons may eventually pass from the lower bed into an optional stripping section. The stripped spent catalyst leaves the first reactor vessel 132 with a lower concentration of entrained or adsorbed hydrocarbons than it had when it entered or if it had not been subjected to stripping. A first portion of the spent catalyst, preferably stripped, leaves the first reactor vessel 132 and passes into the regenerator vessel 104 at a rate regulated by a slide valve. The regenerator 104 is in downstream communication with the first reactor 102. A second portion of the spent catalyst is recirculated to the first reactor 102 at a rate regulated by a slide valve to recontact the feed without undergoing regeneration.

[0030] The regenerator vessel 104 is in downstream communication with the first reactor vessel 132. In the regenerator vessel 104, coke is combusted from the portion of spent catalyst delivered to the regenerator vessel 104 by contact with an oxygen-containing gas such as air to provide regenerated catalyst. The regenerator vessel 104 may be a combustor

type of regenerator as shown in FIG. 1, but other regenerator vessels and other flow conditions may be suitable for the present invention. The oxygen in the combustion gas contacts the spent catalyst and combusts carbonaceous deposits from the catalyst to at least partially regenerate the catalyst and generate flue gas.

[0031] As discussed previously herein, the first cracked products in the line 140 from the first reactor 102 are relatively free of catalyst particles and includes the stripping fluid. The cracked products exit the first reactor vessel 132 and may optionally be subjected to additional treatment to remove fine catalyst particles or to further prepare the stream prior to fractionation. The line 140 transfers the first cracked products stream to the product fractionation section 106, which in one embodiment, may include a main fractionation column 150 and a gas recovery section (not shown).

[0032] The main fractionation column 150 is a fractionation column with trays and/or packing positioned along its height for vapor and liquid to contact and reach equilibrium proportions at tray conditions and a series of pump-arounds to cool the contents of the main column. The main fractionation column 150 is in downstream communication with the first reactor 102 and can be operated with a top pressure of 35 to 350 kPa (gauge) (5 to 50 psig) and a bottom temperature of 343°C to 399°C. (650°F to 750°F.).

[0033] A variety of products are withdrawn from the main fractionation column 150. For example, one or more product streams 152 are recovered from the fractionation column 150 and may be further processed. Another (second) feed 154, typically a C_4-C_{12} stream, is recovered from the fractionation column 150 and further processed. The feed 154 may be subjected to vaporization in an evaporator (not shown) and/or mixed with other streams to form a second hydrocarbon feed. The second feed 154 is delivered to the second catalytic reactor 110 that is in downstream communication with an overhead of the main fractionation column 150.

[0034] The second catalytic reactor 110 may be a second FCC reactor. The second feed 154 may be at least partially comprised of C_{10}-hydrocarbons, preferably comprising C_4 to C_7 olefins. The second feed 154 predominantly comprises hydrocarbons with 12 or fewer carbon atoms and preferably between 4 and 12 carbon atoms. The second feed 154 preferably

comprises a portion of the first cracked products produced in the first reactor 102, fractionated in the main column 150 and provided to the second reactor 110.

[0035] The second reactor 110 includes a second riser 160. The second feed 154 is contacted with catalyst delivered to the second reactor 110 by a catalyst return standpipe 162 in upstream communication with the second riser 160 to produce cracked upgraded products. The catalyst may be fluidized by inert gas such as steam from a distributor 164. Generally, the second reactor 110 may operate under conditions to convert the light naphtha feed to smaller hydrocarbon products. C_4-C_7 olefins crack into one or more light olefins, such as ethylene and/or propylene. A second reactor vessel 166 is in downstream communication with the second riser 160 for receiving upgraded products and catalyst therefrom. The mixture of gaseous, upgraded product hydrocarbons and catalyst continues upwardly through the second riser 160 and is received in the second reactor vessel 166 in which the catalyst and gaseous hydrocarbon, upgraded products are separated.

[0036] The second riser 160 for use in the FCC process 100 herein preferably includes a specialized design that increases the yield of light olefins (e.g., polypropylene) from the second hydrocarbon feed 154. Referring more particularly to FIGS. 2-5, the second riser 160 is defined by a housing 180 having an exterior surface 182 and an interior surface 184. The second riser 160 includes a lower entry conduit 186 and an upper exit conduit 188 with a holdup chamber 190 disposed therebetween.

[0037] The lower entry conduit 186 is designed to supply the second feed 154 and/or the catalyst through the holdup chamber 190, out of the exit conduit 188, and into the second reactor vessel 166. As the second feed 154 travels through the second riser 160, catalyst contacts the second feed 154 to produce one or more light olefins, such as ethylene and/or propylene. In particular, the holdup chamber 190 is designed to accommodate the hydrocarbon feed (not shown) as it contacts a catalyst (not shown) and is cracked into a product stream (not shown) containing lighter hydrocarbons. The catalyst and the hydrocarbon feed are transported upwardly in the second riser 160 by the expansion of the gases that result from the vaporization of the hydrocarbons, and other fluidizing mediums, upon contact with the hot catalyst.

[0038] The holdup chamber 190 is characterized by a specially designed shape that increases the catalyst/feed 154 residence time within the second riser 160. The holdup chamber 190 may be designed in a variety of ways so long as at least one portion of the chamber 190 protrudes outwardly from one or more of the lower entry conduit 186 and/or the upper exit conduit 186. In one embodiment shown in FIG. 2, the holdup chamber 190 is defined by a substantially cylindrical body 200 having a flat upper surface 202 and a flat lower surface 204. In a further embodiment depicted in FIG. 3, the holdup chamber 190 is defined by a smaller cylindrical section 206 that is truncated by opposing first and second curved ends 208, 210.

[0039] In a different embodiment, as best seen in FIGS. 4 and 5, the holdup chamber 190 includes a protruding section 220 having an angled lower surface 222 and an angled upper surface 224 with a straightened section 226 therebetween. The lower surface 222 is defined by an angle A of between 10 degrees to 85 degrees as determined from a transverse axis T perpendicular to a longitudinal axis L of the second riser 160. In one embodiment, the angle A is between 20 degrees to 75 degrees. In a different embodiment, the angle A is between 30 degrees to 60 degrees. In a further embodiment, the angle A is between 40 degrees to 50 degrees. In one particular embodiment, the angle A is 40 degrees. In a different embodiment, the angle A is 45 degrees. In a further embodiment, the angle A is 50 degrees.

[0040] Similarly, the angled upper surface 224 is defined by an angle B of between 10 degrees to 85 degrees as determined from a transverse axis T perpendicular to the longitudinal axis L of the second riser 160. In one embodiment, the angle B is between 20 degrees to 75 degrees. In a different embodiment, the angle B is between 30 degrees to 60 degrees. In a further embodiment, the angle B is between 40 degrees to 50 degrees. In one particular embodiment, the angle B is 40 degrees. In a different embodiment, the angle B is 45 degrees. In a further embodiment, the angle B is 50 degrees. In one embodiment, the angles A and B are preferably substantially the same. In another embodiment, the angles A and B are different.

[0041] The angling of both the upper surface 224 and the lower surface 222 is designed in a manner that disrupts the flow of the catalyst along the interior surface 184 of the second riser 160. Namely, as the catalyst travels upwardly through the second riser 166, the catalyst travels upwardly along the interior surface 184 adjacent the lower angled surface 222. Once

entering the holdup chamber 190, the catalyst is dispersed outwardly toward the straightened section 226. The holdup chamber 190 retains the catalyst and second feed 154 for a residence time typically longer than that currently known in the art. In particular, the residence time is typically between 1 to 10, or more particularly between 2 to 5, and most preferably 3 seconds. After leaving the holdup chamber 190, the propylene and other product exit the second riser 160 through the exit conduit 188 into the second reactor vessel 166.

[0042] The straightened section 226 of the second riser 160 preferably includes a height dimension H (see FIG. 5) of between 1.52 meters (5 ft.) to 9.14 meters (30 ft.) as measured from a first point 240 adjacent the intersection of the lower surface 222 and the straightened section 226 to a second point 242 adjacent the intersection of the upper surface 224 and the straightened section 226. The height H is between 1.52 meters (5 ft.) to 9.14 meters (30 ft.). In a different embodiment, the height H is between 3.05 meters (10 ft.) to 6.1 meters (20 ft.). In a further embodiment, the height H is between 3.81 meters (12.5 ft.) to 5.33 meters (17.5 ft.). In one particular embodiment, the height H is between 4.57 meters (15 ft.) to meters 4.88 (16 ft.).

[0043] The second riser 160 includes a total length dimension L that is between 3.05 meters (10 ft.) to 60.96 meters (200 ft.). In a different embodiment, the length dimension L is between 15.24 meters (50 ft.) to 30.48 meters (100 ft.). In a further embodiment, the length dimension is between 22.86 meters (75 ft.) to 30.48 meters (100 ft.).

[0044] The holdup chamber 190 includes a width dimension W at centerpoint 244 that is between 0.61 meters (24 inches) to 3.66 meters (144 inches). In another embodiment, the width W is between 0.91 meters (36 inches) to 3.05 meters (120 inches). In a different embodiment, the width W is between 1.22 meters (48 inches) to 2.44 meters (96 inches). In a further embodiment, the width W is between 1.52 meters (60 inches) to 1.83 meters (72 inches). In one particular embodiment, the width W is between 1.65 meters (65 inches) to 1.78 meters (70 inches). The holdup chamber 190 further includes a volume dimension V of between 1133 liters (40 ft^3) to 45,307 liters (1600 ft^3). In another embodiment, the volume dimension V is between 2832 liters (100 ft^3) to 33,980 liters (1200 ft^3). In a different embodiment, the volume dimension V is between 7079 liters (250 ft^3) to 21,238 liters (750 ft^3). In one particular embodiment, the volume dimension V is between 11,327 liters (400 ft^3) to 12,743 liters (450 ft^3).

[0045] Similarly, the lower entry conduit 186 and the exit conduit 188 each have width dimensions W_1 and W_2, respectively, that are smaller than that of the holdup chamber 190. The width W_1 is between 0.305 meters (12 inches) to 1.83 meters (72 inches). In a different embodiment, the width W_1 is between 0.61 meters (24 inches) to 1.52 meters (60 inches). In a further embodiment, the width W_1 is between 0.91 meters (36 inches) to 1.22 meters (48 inches). In one particular embodiment, the width W_1 is between 1.02 meters (40 inches) to 1.14 meters (45 inches). The width W_2 is between 0.305 meters (12 inches) to 1.83 meters (72 inches). In a different embodiment, the width W_2 is between 0.61 meters (24 inches) to 1.52 meters (60 inches). In a further embodiment, the width W_2 is between 0.91 meters (36 inches) to 1.22 meters (48 inches). In one particular embodiment, the width W_2 is between 1.02 meters (40 inches) to 1.14 meters (45 inches). In one embodiment, the width W_1 of the lower entry conduit 186 is different from the width W_2 of the exit conduit 188. In a different embodiment, the width W_1 of the lower entry conduit 186 is substantially similar to the width W_2 of the exit conduit 188.

[0046] The ratio of the width dimension W of the holdup chamber 190 to the width dimensions W_1 and W_2 (riser inside diameters) of the lower entry conduit 186 and the exit conduit 188 are between 1.1 to 4.0. In another embodiment, the ratio is between 1.5 to 3.0. In a further embodiment, the ratio is between 1.8 to 2.2.

[0047] The ratio of the height dimension H to the width dimension W (riser inside diameter) of the holdup chamber 190 is between 0.4 to 15. In another embodiment, the ratio is between 3 to 12. In a further embodiment, the ratio is between 5 to 9.

[0048] The ratio of the height dimension H to the width dimensions W_1 and W_2 (riser inside diameters) of the lower entry conduit 186 and the exit conduit 188 are between 0.8 to 30. In another embodiment, the ratio is between 5 to 25. In a further embodiment, the ratio is between 10 to 20.

[0049] The ratio of the total length dimension L to the width dimension W (riser inside diameter) of the holdup chamber 190 is between 0.8 to 100. In another embodiment, the ratio is between 20 to 80. In a further embodiment, the ratio is between 40 to 60.

[0050] The ratio of the total length dimension L to the width dimensions W_1 and W_2 (riser inside diameters) of the lower entry conduit 186 and the exit conduit 188 are between

1.6 to 200. In another embodiment, the ratio is between 40 to 160. In a further embodiment, the ratio is between 80 to 120.

[0051] The speed at which the catalyst and second feed 154 travel through the second riser 160 varies therethrough. In particular, as the second feed 154 enters the lower entry conduit 186, the velocity is between 1.5 m/sec to 8 m/sec, more preferably between 3 m/sec and 6 m/sec, and most preferably 4 to 5 m/sec. As the catalyst and second feed 154 enter the holdup chamber 190, the velocity decreases. In particular, the velocity of the second feed 154 and catalyst traveling through the holdup chamber 190 is between 0.5 m/sec to 15 m/sec, more preferably between 1 m/sec to 9 m/sec, and most preferably 4 to 5 m/sec. As the feed 154 and catalyst exit the holdup chamber 190, the velocity increases. Namely, the velocity increases to between 12 m/sec to 28 m/sec, more preferably between 15 m/sec to 22 m/sec, and most preferably 17 to 19 m/sec.

[0052] The second riser 160 can operate in any suitable condition, such as a temperature between 500°C and 600°C, preferably between 520°C and 580°C, and more preferably between 540°C and 560°C. The pressure in the second riser 160 may be any suitable pressure, such as, a pressure of 30 to 200 kPa(g), preferably a pressure of 50 to 100 kPa(g), and more preferably a pressure of 60 to 70 kPa(g).

[0053] The feed 154 and/or catalyst may enter the riser 160 through a variety of entry points disposed along the riser 160. The entry points are preferably openings that are in communication with one or more of the feed and or catalyst lines. For example, the feed 154 and/or catalyst may enter the riser 160 at a point along the entry conduit 186. In a different embodiment, the feed 154 and/or catalyst may enter the riser 160 through the holdup chamber 190, and more particularly, through the lower angled surface 222 of the holdup chamber 190. In one particular embodiment, the feed 154 enters the riser 160 at a point E, shown on FIG. 5. In a different embodiment, the feed 154 enters the riser 160 at a point E_1 adjacent the lower angled surface 222.

[0054] The mixture of gas and catalyst are discharged from a top of the second riser 160 through one or more outlet ports into the second reactor vessel 166 that effects partial separation of gases from the catalyst. The catalyst can drop to a dense catalyst bed within the second reactor vessel 166. Cyclones (not shown) in the second reactor vessel 166 may further

separate catalyst from second cracked products. Afterwards, the second cracked hydrocarbon products can be removed from the second reactor 110 through an outlet 250 in downstream communication with the second riser 160 through a second cracked products line 260. Separated catalyst may be recycled via the recycle catalyst standpipe 162 from the second reactor vessel 166 regulated by a control valve back to the second riser 160 to be contacted with the second feed 154. After exiting the second reactor 166, the second products travel through line 260 and are directed to the second product recovery section 112.

SPECIFIC EMBODIMENTS

[0055] While the following is described in conjunction with specific embodiments, it will be understood that this description is intended to illustrate and not limit the scope of the preceding description and the appended claims.

[0056] A first embodiment of the invention is a riser, comprising a housing in communication with an entry conduit and an exit conduit, wherein the housing is defined by a holdup chamber having a volume of between 1133 liters to 45307 liters, and wherein the housing is designed to receive a hydrocarbon feed and a catalyst. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph, wherein the width dimension of the holdup chamber is greater than the width dimension of at least one of the entry conduit or exit conduits. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph, wherein the width dimension of the holdup chamber is greater than the width dimension of both of the entry conduit and exit conduits. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph, wherein the holdup chamber includes an angled lower surface and an angled upper surface. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph, wherein the angled lower surface and the angled upper surface are each characterized by an angle of between 20 degrees to 60 degrees. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph, wherein the holdup chamber disrupts the flow of the catalyst along an interior surface thereof.

[0057] A second embodiment of the invention is an apparatus for fluid catalytic cracking, the apparatus comprising a riser in communication with a reactor vessel designed to receive a feed stream and a catalyst, wherein the feed stream and the catalyst travel through a first section of the riser at a first velocity of between 1.5 m/sec to 10 m/sec and through a second section of the riser at a second velocity of more than 15 m/sec. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph, wherein the feedstream comprises C_4 to C_7 olefins. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph, wherein the catalyst comprises a zeolite. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph, wherein the feed stream reacts with the catalyst to form polypropylene. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph, wherein the feed stream comprises a previously cracked feed. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph, wherein the riser is defined by a holdup chamber. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph, wherein the holdup chamber includes a protruding section that increases the residence time of the feed stream and the catalyst therein. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph, wherein the holdup chamber includes at least one angled surface disposed adjacent an upper or lower surface. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph, wherein both an upper and a lower surface of the holdup chamber are angled. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph, wherein the volume dimension of the holdup chamber is 1133 liters to 45307 liters. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph, wherein the first section of the riser is the holdup chamber.

[0058] A third embodiment of the invention is a process for fluid catalytic cracking, the process comprising (a) providing a riser comprising a housing in fluid communication with

an entry conduit and an exit conduit, wherein the housing is defined by a holdup chamber; and (b) directing a hydrocarbon feed and a catalyst through the entry conduit, the housing, and the exit conduit of the riser, wherein a velocity of the hydrocarbon feed and the catalyst decreases in the holdup chamber such that the velocity of the hydrocarbon feed and the catalyst is between 1.5 m/sec and 10 m/sec as the feed and catalyst are traveling through the holdup chamber. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the third embodiment in this paragraph, wherein the velocity of the hydrocarbon feed and the catalyst is less than 4.5m/sec as the feed and catalyst enter the entry conduit. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the third embodiment in this paragraph, wherein a residence time of the hydrocarbon feed and the catalyst in the holdup chamber is between 0.5 to 5.0 seconds.

[0059] While the foregoing written description of the invention enables one of ordinary skill to make and use what is considered presently to be the best mode thereof, those of ordinary skill will understand and appreciate the existence of variations, combinations, and equivalents of the specific exemplary embodiments thereof. The invention is therefore to be limited not by the exemplary embodiments herein, but by all embodiments within the scope and spirit of the appended claims.

[0060] Without further elaboration, it is believed that one skilled in the art can, using the preceding description, utilize the present invention to its fullest extent. The preceding preferred specific embodiments are, therefore, to be construed as merely illustrative, and not limitative of the remainder of the disclosure in any way whatsoever.

[0061] In the foregoing, all temperatures are set forth in degrees Celsius and, all parts and percentages are by weight, unless otherwise indicated. Additionally, control valves expressed as either open or closed can also be partially opened to allow flow to both alternative lines.

WE CLAIM:

1. A riser, comprising:

a housing in communication with an entry conduit and an exit conduit,

wherein the housing is defined by a holdup chamber having a volume of between 1133 liters to 45307 liters, and wherein the housing is designed to receive a hydrocarbon feed and a catalyst.

2. The riser of claim 1, wherein the width dimension of the holdup chamber is greater than the width dimension of at least one of the entry conduit or exit conduits.

3. The riser of claim 1, wherein the holdup chamber includes an angled lower surface and an angled upper surface.

4. The riser of claim 3, wherein the angled lower surface and the angled upper surface are each characterized by an angle of between 20 degrees to 60 degrees.

5. An apparatus for fluid catalytic cracking, the apparatus comprising:

a riser in communication with a reactor vessel designed to receive a feed stream and a catalyst,

wherein the feed stream and the catalyst travel through a first section of the riser at a first velocity of between 1.5 m/sec to 10 m/sec and through a second section of the riser at a second velocity of more than 15 m/sec.

6. The apparatus of claim 5, wherein the riser is defined by a holdup chamber.

7. The apparatus of claim 6, wherein the holdup chamber includes a protruding section that increases the residence time of the feed stream and the catalyst therein.

8. The apparatus of claim 6, wherein both an upper and a lower surface of the holdup chamber are angled.

9. A process for fluid catalytic cracking, the process comprising:

(a) providing a riser comprising a housing in fluid communication with an entry conduit and an exit conduit, wherein the housing is defined by a holdup chamber; and

(b) directing a hydrocarbon feed and a catalyst through the entry conduit, the housing, and the exit conduit of the riser,

wherein a velocity of the hydrocarbon feed and the catalyst decreases in the holdup chamber such that the velocity of the hydrocarbon feed and the catalyst is between 1.5 m/sec and 10 m/sec as the feed and catalyst are traveling through the holdup chamber.

10. The process of claim 9, wherein the velocity of the hydrocarbon feed and the catalyst is less than 4.5m/sec as the feed and catalyst enter the entry conduit, and wherein a residence time of the hydrocarbon feed and the catalyst in the holdup chamber is between 0.5 to 5.0 seconds.

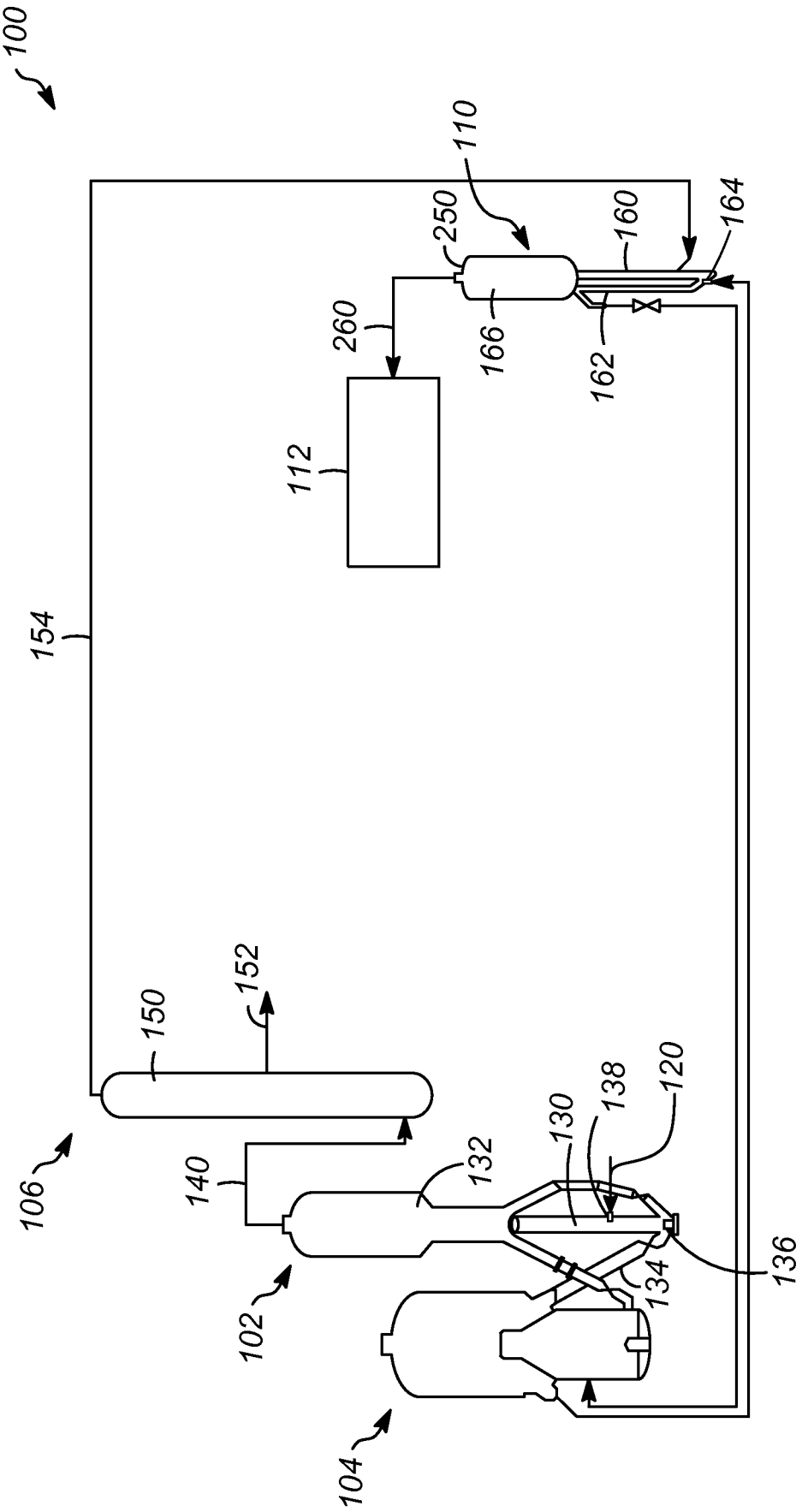
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FIG. 1

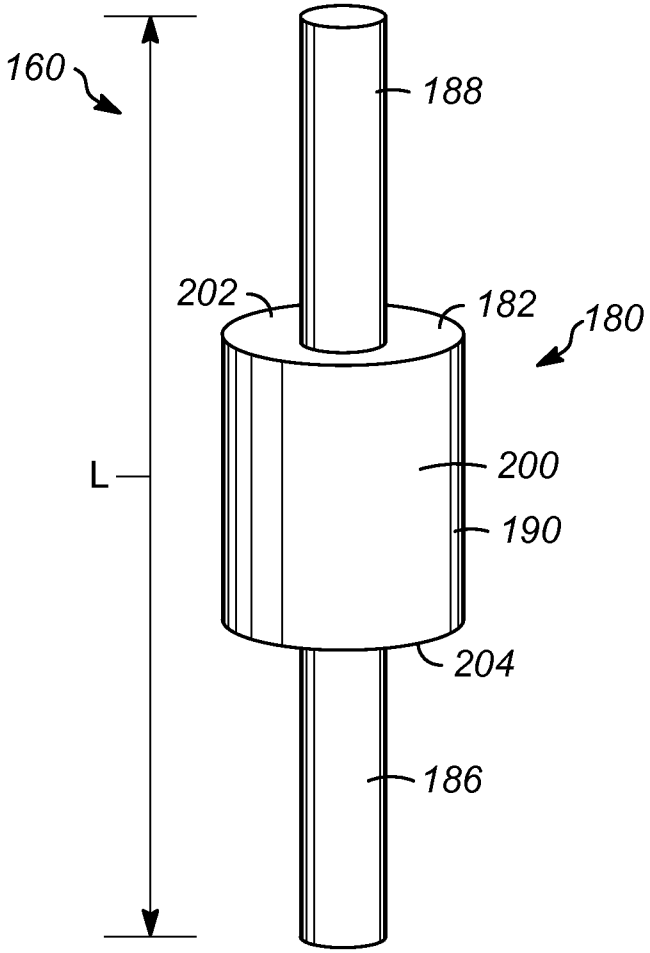
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FIG. 2

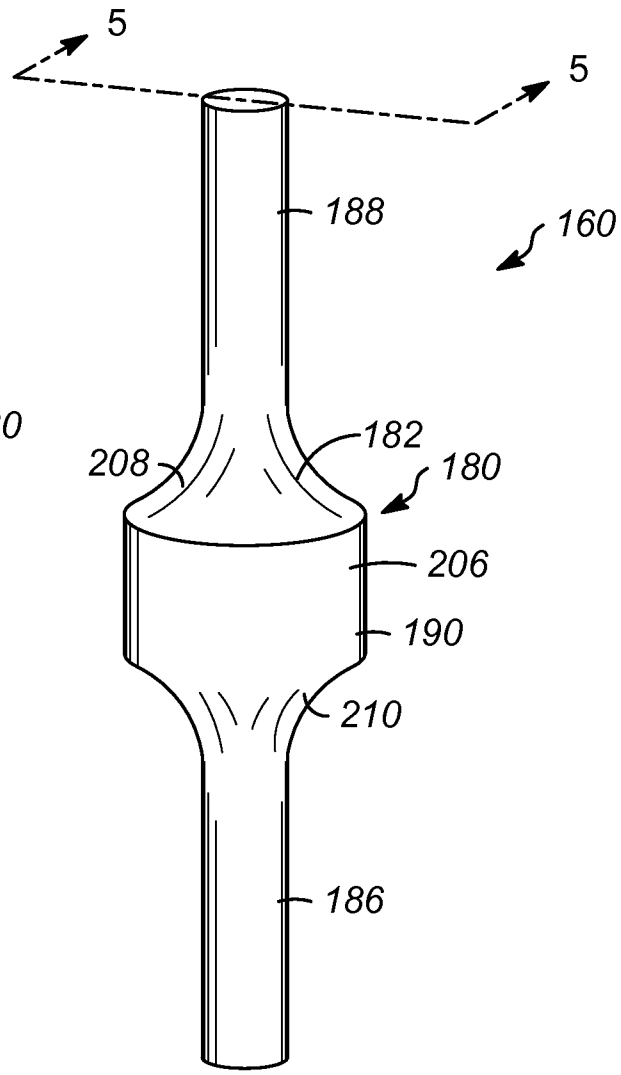
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FIG. 3

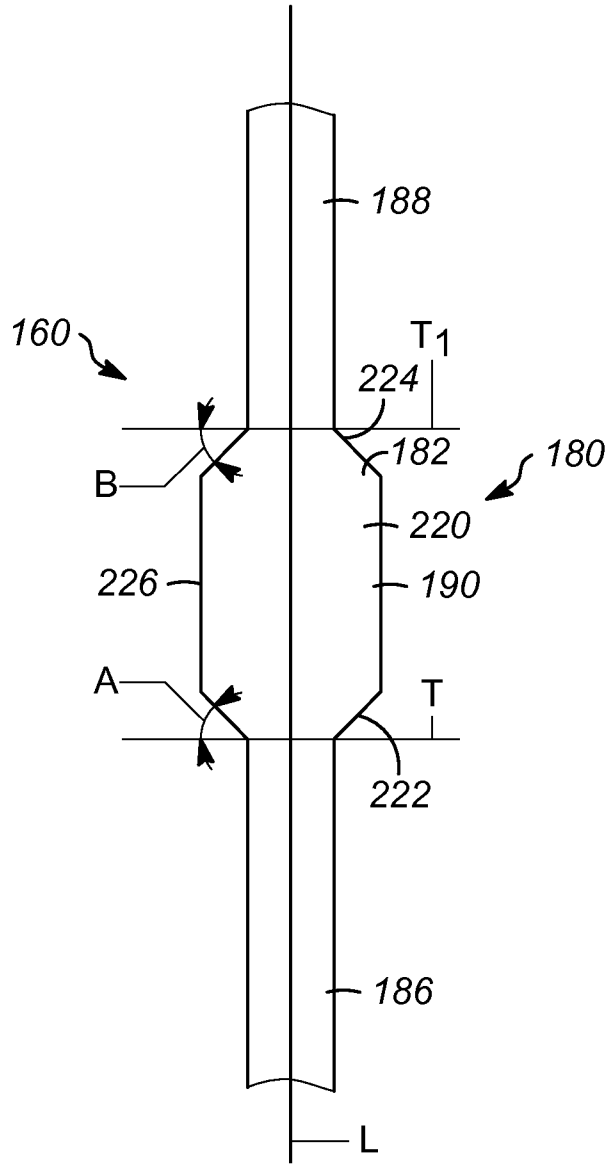
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FIG. 4

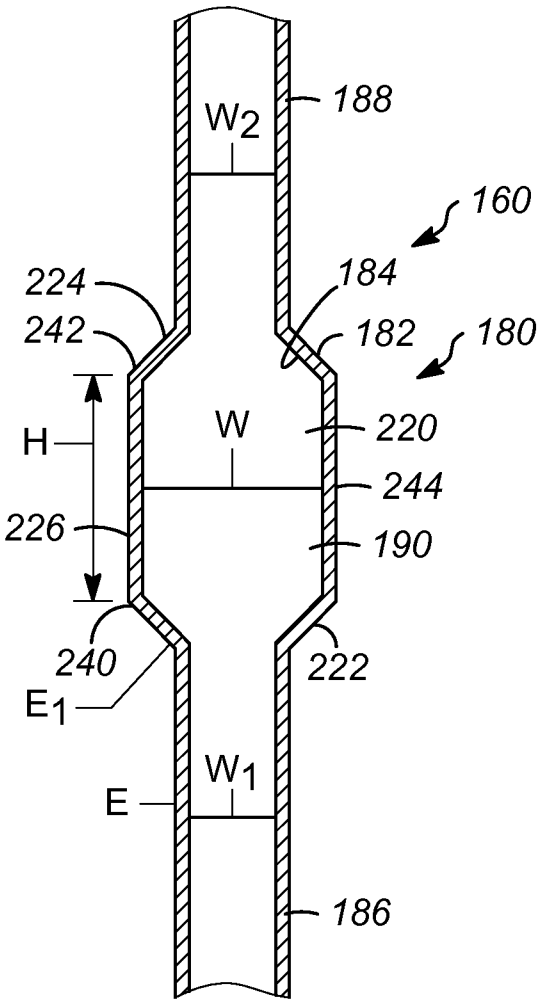
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FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/036903

A. CLASSIFICATION OF SUBJECT MATTER

B01J 8/18(2006.01)i, B01J 8/08(2006.01)i, B01J 19/24(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B01J 8/18; C10G 11/18; C10G 11/00; B01J 8/04; B01J 8/00; B01J 8/24; B01J 8/08; B01J 19/24

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: riser, housing, holdup chamber, fluid catalytic cracking, reactor vessel, volume, velocity, hydrocarbon, catalyst

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 102417827 A (CHINA PETROLEUM & CHEMICAL et al.) 18 April 2012 See paragraphs [0023], [0024], [0035], [0037], [0050], [0055]; claims 1, 10, 11; and figures 1, 2.	1-10
A	US 4797262 A (DEWITZ, T. S.) 10 January 1989 See column 3, line 22 - column 4, line 35, column 9, lines 6 - 8, column 12, lines 5 - 21, column 15, line 58 - column 16, line 7; claim 1; and figure 3.	1-10
A	US 3957443 A (STRICKLAND, J. C. et al.) 18 May 1976 See abstract; column 6, line 12 - column 7, line 60; claim 1; and figure 1.	1-10
A	US 5368721 A (TERRY, P. H. et al.) 29 November 1994 See abstract; column 2, line 57 - column 5, line 31, column 6, line 65 - column 7, line 29; claim 1; and figures 1 - 2C.	1-10
A	US 2011-0110825 A1 (LEONARD, L. E. et al.) 12 May 2011 See abstract; paragraphs [0026], [0027], [0034], [0049], [0052]; and figure 1.	1-10

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 August 2014 (19.08.2014)	**20 August 2014 (20.08.2014)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2014/036903

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
CN 102417827 A	18/04/2012	CN 102417828 A	18/04/2012
		JP 2013537926 A	07/10/2013
		KR 10-2014-0000223 A	02/01/2014
		TW 201224133 A	16/06/2012
		US 2013-211167 A1	15/08/2013
US 4797262 A	10/01/1989	CN 1013870 B	11/09/1991
		CN 1016488 C	01/01/1992
		CN 87104227 A	17/02/1988
		EP 0254333 A1	27/01/1988
		JP 02523325 B2	07/08/1996
		JP 2017-523325 B	07/08/1996
		JP 63004840 A	09/01/1988
		US 4693808 A	15/09/1987
US 3957443 A	18/05/1976	US 3959117 A	25/05/1976
US 5368721 A	29/11/1994	EP 0705320 A1	20/11/2002
		EP 0705320 A4	12/06/1996
		JP 09502465 A	11/03/1997
		US 5591411 A	07/01/1997
		WO 95-00603 A1	05/01/1995
US 2011-0110825 A1	12/05/2011	CN 102549113 A	04/07/2012
		KR 10-1304041 B1	04/09/2013
		US 2011-0108458 A1	12/05/2011
		US 8354018 B2	15/01/2013
		US 8506891 B2	13/08/2013
		WO 2011-056691 A2	12/05/2011
		WO 2011-056691 A3	22/09/2011