PROCESS FOR CONVERSION OF HYDROCARBONS INTEGRATING REFORMING USING A NON-NOBLE METAL CATALYST AND DEHYDROCYCLODIMERIZATION

Publication Classification

Int. Cl.  
C10G 57/00  (2006.01)  
C10G 2400/30  (2013.01)

U.S. Cl.  
CPC ........... C10G 57/00 (2013.01); C10G 2400/30 (2013.01)

ABSTRACT

The present subject matter relates generally to methods for hydrocarbon conversion. More specifically, the present subject matter relates to methods for integrating reforming and dehydrocyclodimerization, which are both catalytic processes. While dehydrocyclodimerization takes two or more molecules of a light aliphatic hydrocarbon, such as propane or propylene, to form a product aromatic hydrocarbon and hydrogen, platforming takes C6 and higher carbon number reactants, primarily paraffins and naphthenes, to convert to aromatics and hydrogen. This integration enables an opportunity to recombine the light aliphatic hydrocarbon from the platforming process into a more desirable aromatics species.
PROCESS FOR CONVERSION OF HYDROCARBONS INTEGRATING REFORMING USING A NON-NOBLE METAL CATALYST AND DEHYDROCYCLODIMERIZATION

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority from Provisional Application No. 62/187,185 filed Jun. 30, 2015, the contents of which are hereby incorporated by reference.

FIELD

[0002] The present subject matter relates generally to methods for hydrocarbon conversion. More specifically, the present subject matter relates to methods for integrating reforming and dehydrocyclodimerization, which are both catalytic processes. While dehydrocyclodimerization takes two or more molecules of a light aliphatic hydrocarbon, such as propane or propylene, to form a product aromatic hydrocarbon and hydrogen, platforming takes C₅ and higher carbon number reactants, primarily paraffins and naphthenes, to convert to aromatics and hydrogen.

BACKGROUND

[0003] Catalytic reforming applications carry yield losses due to catalytic cracking on the platinum impregnated alumina surface which becomes more prevalent at higher severity operations used to increase aromatics yield. Therefore operating conditions used to maximize aromatic yields by increasing severity tend to produce higher amounts of a byproduct stream in the C₅-C₈ range, which has a lower value than the C₆₊ feedstock and is unable to convert to aromatics in reforming. For these reasons, platforming unit operations are typically operated under partial conversion of these components in an effort to preserve a gasoline blendstock byproduct from the aromatics complex. Here, the dehydrocyclodimerization process provides an opportunity to recombine the light aliphatic hydrocarbons from the continuous catalytic reforming process into a more desirable aromatics species.

[0004] Dehydrocyclodimerization is a process in which aliphatic hydrocarbons are reacted over a catalyst to produce aromatics, hydrogen and certain byproducts. This process is distinct from more conventional reforming where C₅ and higher carbon number reactants, primarily paraffins and naphthenes, are converted to aromatics. The aromatics produced by conventional reforming contain the same or a lesser number of carbon atoms per molecule than the reactants from which they were formed, indicating the absence of reactant oligomerization reactions. In contrast, the dehydrocyclodimerization reaction results in an aromatic product that typically contains more carbon atoms per molecule than the reactants, thus indicating that the oligomerization reaction is a mandatory reaction step in the dehydrocyclodimerization process. Typically, the dehydrocyclodimerization reaction is carried out at temperatures in excess of 350° C. using dual functional catalysts containing acidic and dehydrogenation components.

[0005] Aromatics, hydrogen, a C₅₊ nonaromatics byproduct, and a light ends byproduct are all products of the dehydrocyclodimerization process. The aromatics are the desired product of the reaction as they can be utilized as gasoline blending components or for the production of petrochemicals. Hydrogen is also a desirable product of the process. The hydrogen can be efficiently utilized in hydrogen consuming refinery processes such as hydrotreating or hydrocracking processes. The least desirable product of the dehydrocyclodimerization process is light ends byproducts. The light ends byproducts consist primarily of C₁ and C₂ hydrocarbons produced as a result of the cracking side reactions.

SUMMARY

[0006] A hydrocarbon conversion process, comprising a) passing a first hydrocarbon stream to a reforming zone having a first catalyst wherein the reforming zone operates at reforming zone conditions to produce a reforming zone effluent stream, and b) passing the reforming zone effluent stream to a dehydrocyclodimerization zone having a second catalyst wherein the dehydrocyclodimerization zone operates at a dehydrocyclodimerization zone effluent. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph, further comprising passing the dehydrocyclodimerization zone effluent to an aromatics recovery zone. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph, further comprising passing the dehydrocyclodimerization zone effluent to an aromatics recovery zone. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph, further comprising passing the dehydrocyclodimerization zone effluent to an aromatics recovery zone. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph, further comprising passing the dehydrocyclodimerization zone effluent to an aromatics recovery zone.

[0007] Additional objectives, advantages and novel features of the examples will be set forth in part in the description which follows, and in part will become apparent to those skilled in the art upon examination of the following description and the accompanying drawings or may be learned by production or operation of the examples. The objectives and advantages of the concepts may be realized and attained by means of the methodologies, instrumentalities and combinations particularly pointed out in the appended claims.

DEFINITIONS

[0008] As used herein, the term “dehydrocyclodimerization” is also referred to as aromatization of light paraffins. Within the subject disclosure, dehydrocyclodimerization and aromatization of light hydrocarbons are used interchangeably.

[0009] As used herein, the term “stream”, “feed”, “product”, “part” or “portion” can include various hydrocarbon molecules, such as straight-chain, branched, or cyclic alkanes, alkenes, alkadienes, and alkynes, and optionally other substances, such as gases, e.g., hydrogen, or impurities, such as heavy metals, and sulfur and nitrogen compounds. The stream can also include aromatic and non-aromatic hydrocarbons. Moreover, the hydrocarbon molecules may be abbreviated C₁, C₂, C₃, Cₙ where “n” represents the number of carbon atoms in the one or more hydrocarbon molecules or the abbreviation may be used as an adjective for, e.g., non-aromatics or compounds. Similarly, aromatic compounds may be abbreviated A₆, A₇, A₈,
An where “n” represents the number of carbon atoms in the one or more aromatic molecules. Furthermore, a superscript “+” or “−” may be used with an abbreviated one or more hydrocarbons notation, e.g., C_{8+} or C_{8−}, which is inclusive of the abbreviated one or more hydrocarbons. As an example, the abbreviation “C_{8+}” means one or more hydrocarbon molecules of three or more carbon atoms.

As herein, the term “zone” can refer to an area including one or more equipment items and/or one or more sub-zones. Equipment items can include, but are not limited to, one or more reactors or reactor vessels, separation vessels, distillation towers, heaters, exchangers, pipes, pumps, compressors, and controllers. Additionally, an equipment item, such as a reactor, dryer, or vessel, can further include one or more zones or sub-zones.

As herein, the term “rich” can mean an amount of at least generally 50%, and preferably 70%, by mole, of a compound or class of compounds in a stream.

As herein, the term “substantially” can mean an amount of at least generally 80%, preferably 90%, and optimally 99%, by mole or weight, of a compound or class of compounds in a stream.

As herein, the term “active metal” can include metals selected from IUPAC Groups that include 6, 7, 8, 9, 10, and 13 such as chromium, molybdenum, tungsten, rhenium, platinum, palladium, rhodium, iridium, ruthenium, osmium, copper, zinc, silver, gallium, and indium.

As herein, the term “modifier metal” can include metals selected from IUPAC Groups that include 11-17. The IUPAC Group 11 trough 17 includes without limitation sulfur, gold, tin, germanium, and lead.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawing figures depict one or more implementations in accord with the present concepts, by way of example only, not by way of limitations. In the figures, like reference numerals refer to the same or similar elements.

FIG. 1 is a schematic depiction of an exemplary aromatic production process in accordance with various embodiments for the production of aromatics.

FIG. 2 is a schematic depiction of another exemplary aromatic production process in accordance with various embodiments for the production of aromatics.

DETAILED DESCRIPTION

The following detailed description is merely exemplary in nature and is not intended to limit the application and uses of the embodiment described. Furthermore, there is no intention to be bound by any theory presented in the preceding background or the following detailed description.

The various embodiments described herein relate to methods for hydrocarbon conversion. More specifically, the present subject matter relates to methods for integrating reforming and a catalytic process referred to as dehydrocyclodimerization wherein two or more molecules of a light aliphatic hydrocarbon, such as, for example, propane or propylene, are joined together to form an aromatic hydrocarbon product. The basic utility of the process is the conversion of the low cost and highly available light aliphatic hydrocarbons, for example, C₃ and C₄ hydrocarbons, into more valuable aromatic hydrocarbons and hydrogen. This may be desired simply to upgrade the value of the hydrocarbons. It may also be desired to capitalize on a large supply of the C₃ and C₄ hydrocarbons or to fulfill a need for the aromatic hydrocarbons. The dehydrocyclodimerization process may also be used to convert C₁₂ and C₁₆ hydrocarbons generated in the platforming units. The aromatic hydrocarbons produced can be used for various applications, including in the production of a wide range of petrochemicals, including benzene, toluene, and xylene, widely used basic feed hydrocarbon chemicals. The product aromatic hydrocarbons are also useful as blending components in high octane number motor fuels.

As illustrated in FIG. 1, the feed 102 to the reforming zone 130 may comprise of C₈-C₁₀ hydrocarbons. The reforming zone 130 includes one or more reactors, feed exchangers, and heaters for raising the temperature of the reactants as they pass to the reactors. Reaction products from the reforming zone 130 typically include a significant amount of hydrogen as well as other light ends material such as butane, propane, ethane, and methane. After purification of hydrogen rich gas, condensate liquids are passed into a stripping column where light ends such as ethane, propane, and butane are removed overhead while a bottoms stream comprising C₈ hydrocarbons are collected as a product.

The reforming zone 130 is operated in the vapor phase with a catalyst bed temperature in the range of about 400° C. (850° F.) to about 570° C. (1050° F.). Other reforming conditions include pressures generally in the range of about 140 kPag (gauged) (20 psig) to about 6900 kPag (1000 psig), with pressures in the range of about 30 psig to about 500 psig being preferred. In a reforming and dehydrocyclodimerization combination process, a liquid hourly space velocity of about 0.5 to about 5.0 and a hydrogen to hydrocarbon mole ratio in an approximate range of about 1:0 to about 6.0 are typical conditions, with a liquid hourly space velocity in the range of about 1:0 to about 4.0 being preferred in reforming. The reforming zone 130 will typically contain multiple catalyst beds. Practice of this claimed subject matter may require a lower octane number from the reforming zone product such that the operating conditions employed may be less severe than typically employed in a typical reforming zone operating under such conditions.

The catalyst beds in the reforming zone 130 may comprise a reforming catalyst which typically contain one or more Group VIII noble metals (platinum, iridium, rhodium, and palladium) and a halogen such as chlorine and/or fluorine. These components of a catalyst are supported on a porous refractory carrier material such as alumina. Detailed description on catalyst suitable for catalytic reforming may be obtained by reference to U.S. Pat. Nos. 3,740,328, 3,745,112, 3,948, 804, and 4,367,137. Fixed bed or moving bed reactors may be used. The catalyst may, therefore, be present in the form of an extrudate or pellet. In contrast, the preferred physical form of the catalyst for use in a moving bed reaction and regeneration train is in the form of hard spherical particles having a diameter of from about ½ to an inch (0.097 cm) to about ½ of an inch (0.397 cm). Reforming catalyst is available commercially from a number of suppliers, particularly UOP, LLC located in Des Plaines, Ill.

As mentioned above, fixed bed reforming reactors may be used. A moving bed radial flow multi-stage reactor may also be used such as is described in U.S. Pat. Nos.
The dehydrocyclodimerization zone 230 operates under light aliphatic aromatization and alkylation (of aromatics with aliphatic hydrocarbon) conditions. Therefore the reaction zone operating conditions promote both the formation of aromatics from light hydrocarbons such as C₂⁻C₈ paraffins, and naphthenes.

Conditions for aromatization of light hydrocarbons are known to favor low pressures and high temperatures. Hence for the dehydrocyclodimerization typical conditions are described in U.S. Pat. No. 4,642,402 A. The preferred metallic component is gallium as described in the previously cited U.S. Pat. No. 4,180,689. Any suitable catalyst may be utilized such as at least one molecular sieve including any suitable material, e.g., alumino-silicate. The catalyst can include an effective amount of the molecular sieve, which can be a zeolite with at least one pore having a 10 or higher member ring structure and can have one or higher dimension. Typically, the zeolite can have a Si/Al mole ratio of greater than 10:1, preferably 20:1 to 60:1. Preferred molecular sieves can include BEA, MTW, FAU (including zeolite Y in both cubic and hexagonal forms, and zeolite X), MOR, MEL, LTL, ZSM, FAU, ITW, MFI, MEL, or FER. Intergrowth, TUN, IMF, FER, TON, MFS, IWW, EUO, MT, HEU, CHA, ERI, MWW, AEL, AFO, AI, and ITA. Preferably, the zeolite can be MFI, MEL, or FAU intergrowth. TUN, IMF, TTH and/or MTW. Suitable zeolite amounts in the catalyst may range from 1 to 100%, and preferably from 10 to 90%, by weight.

Generally, the aromatization and alkylation catalyst includes at least one metal selected from active metals, and optionally at least one metal selected from modifier metals, and the alkylation catalyst (of aromatic with paraffin) includes optionally no active metals. The total active metal content on the catalyst by weight is about less than 5% by weight. In some embodiments, the preferred total active metal content is less than about 2.5%, in yet in another embodiments the preferred total active metal content is less than 1.5%, still in yet in another embodiment the total active metal content on the catalyst by weight is less than 0.5 wt%. At least one metal is selected from IUPAC Groups that include 6, 7, 8, 9, 10, and 13. The IUPAC Group 7 trough 10 includes without limitation chromium, molybdenum, tungsten, rhodium, palladium, platinum, iridium, ruthenium, osmium, silver, and zinc. The IUPAC Group 13 includes without limitation gallium and indium. In addition to at least one active metal, the catalyst may also contain at least one modifier metal selected from IUPAC Groups 11-17. The IUPAC Group 11 trough 17 includes without limitation sulfur, gold, tin, germanium, and lead.

Aromatization and alkylation conditions, according to the present subject matter, include temperatures ranging from about 350°C to 650°C. In another approach, the aromatization and alkylation conditions may include a temperature between about 400°C (752°F) and about 720°C (1328°F).

Aromatization and alkylation conditions according to the present example include pressures between about 0.1 psia to about 500 psiu. In one approach, the aromatization and alkylation conditions may include pressures under about 200 psia. The aromatization and alkylation conditions in another approach include a pressure between about 5 psiu and about 100 psiu. Without being limited by theory, hydrogen-producing aromatization reactions are normally favored by lower pressures and high temperatures, and accordingly
in one approach conditions may include a pressure under about 70 psia at the outlet of the reaction zones rich in light aliphatic hydrocarbons.

[0033] Turning back to FIG. 1, a feed stream 202 enters the dehydrocyclodimerization zone 230. The dehydrocyclodimerization zone 230 operates under typical aromatization of light hydrocarbon conditions in the presence of a typical aromatization of light hydrocarbon catalyst and produces a dehydrocyclodimerization zone product stream 232. The dehydrocyclodimerization zone 230 may include one or more reactor vessels that contain an aromatization catalyst. These reactors can further be connected with and without additional separation equipment, and they may be connected in series or in parallel. The dehydrocyclodimerization zone 230 may generate at least one outlet stream 232. The dehydrocyclodimerization zone outlet stream 232 may be sent to a separation zone 134.

[0034] In the example illustrated in FIG. 2, there are four reactors in the dehydrocyclodimerization zone 230. However, it is contemplated that there may be one or more reactors. The first reactor 12 contains a first catalyst 44. The feed stream 202 enters the first reactor 44, contacts the first catalyst 44 and forms a first reactor effluent 30. The first reactor effluent 30 enters the second reactor 14, contacts the second catalyst 46 and forms a second reactor effluent 32. The second reactor effluent 32 enters the third reactor 16, contacts the third catalyst 48 and forms a third reactor effluent 34. The third reactor effluent 34 enters the fourth reactor 18, contacts the fourth catalyst 50 and forms the reactor zone effluent 232.

[0035] As discussed previously, the feed stream 202 includes light aliphatic compounds. Light aliphatic compound streams can be introduced to the dehydrocyclodimerization zone 230 in a form that could be liquid, vapor, or a mixture thereof. By way of one example, the fresh portion of a C₃ aliphatic feed may be available in liquid form as liquefied petroleum gas.

[0036] The integration of the reforming zone 130 and the dehydrocyclodimerization zone 230 enables the common use of fractionation section for both process units. This further enables for the feeding of specific components to the different reactors in dehydrocyclodimerization section.

[0037] In one example, the feed stream 202 includes only C₃ rich hydrocarbons. Therefore, only C₃ rich hydrocarbons enter the first reactor 12. Additional streams including only C₄ rich hydrocarbons may also be fed into the downstream reactors. Therefore, the C₃ rich hydrocarbons do not enter the first reactor 12, but the C₄ rich hydrocarbons only enter the second and third, or second, third, and fourth reactors. By feeding the less reactive C₃ rich feed into the first reactor 12 and the more reactive C₄ rich into the second reactors 14 and third reactor 16 or the second reactor 14, the third reactor 16, and the fourth reactor 18, a more desired aromatics yield results.

[0038] This would also result in a reduced undesirable heavy aromatics, a reduced light ends including C₁ and C₂, and minimal pyrolytic coking in the lead reactor and heavy fouling in the lagging reactor, while maximizing C₅ conversions.

[0039] In this example, where a C₄ rich feed is introduced into lagging reactors, where both H₂ and aromatics are present, it greatly diverts the propensity to form butadiene, therefore reducing coke fouling. Furthermore, reducing contact times for C₃ conversions greatly mitigate the heavy aromatics formation, thus yields higher desirable aromatics products and mitigating the heavy fouling in the lag reactors.

It is further recognized that introducing C₃ rich hydrocarbon into the lead reactor allows higher operating temperature and lower pressure to drive the conversion of less reactive C₃ rich hydrocarbon to form aromatics. This also minimizes the generation of coke and thus fouling, and minimizes the production of excessive light ends including C₁ and C₂, derived from the cracking of more reactive C₄.

[0040] In another example, the feed stream 202 includes only C₅ hydrocarbons. Therefore, only C₅ rich hydrocarbons enter the first reactor 12. Additional streams including only C₄ rich hydrocarbons may also be fed into the downstream reactors. Therefore, the C₄ rich hydrocarbons do not enter the first reactor 12, but the C₅ rich hydrocarbons only enter the second and third reactors. A stream including only C₄ rich hydrocarbons may only enter the last reactor.

[0041] In this embodiment, C₃ is introduced into the lag reactors to minimize and eliminate the high propensity to produce pyrolytic coke and heavy fouling in the lead and lag reactors. C₃ is a feed component in the dehydrocyclodimerization technology has difficulty processing at significant percentages in the overall feed.

[0042] In one example, the feed stream 202 includes only C₅ rich hydrocarbons. Therefore, only C₅ rich hydrocarbons enter the first reactor 12. Stream 20 includes only C₅ rich hydrocarbons. Therefore, the C₅ rich hydrocarbons do not enter the first reactor 12, but the C₅ rich hydrocarbons only enter the second reactor 14. Additional streams including only C₄ rich hydrocarbons may also be fed into the downstream reactors. Therefore, the C₄ hydrocarbons only enter the third reactor 16 and the fourth reactor 18.

[0043] In another embodiment C₄, C₅ and C₆ rich hydrocarbons are introduced into reactors to attain descending contact times to maximize the overall aromatics yields with reducing light ends and heavy aromatics yields, while mitigating or eliminating pyrolytic coke and heavy fouling in the lead and lag reactor(s).

[0044] In another example, the feed stream 202 includes only C₆ rich hydrocarbons. Therefore, only C₆ rich hydrocarbons enter the first reactor 12. An additional stream may include only C₅ rich hydrocarbons. Therefore, the C₅ rich hydrocarbons do not enter the first reactor 12, but the C₆ rich hydrocarbons only enter the second reactor 14. An additional stream may include only C₅ rich hydrocarbons. Therefore, the C₅ hydrocarbons only enter the third reactor 16. An additional stream may only include C₅ rich hydrocarbons. Therefore a hydrocarbon stream rich in C₅ hydrocarbons only enters the fourth reactor 18.

[0045] In another embodiment, there may be a recycle stream. The recycle stream may contain C₅-C₆ hydrocarbons. The recycle stream containing C₅-C₆ hydrocarbons may be mixed with the feed but the recycle stream may also enter any or all of the reactors as well. For example, the recycle stream may also enter the second reactor, the third reactor, and the fourth reactor.

[0046] It is contemplated that the first catalyst 44, the second catalyst 46, the third catalyst 48, and the fourth catalyst 50 may be the same. However, it is also contemplated that the first catalyst 44, the second catalyst 46, the third catalyst 48, and the fourth catalyst 50 may be different.

[0047] In the example illustrated in FIG. 2, the reforming zone effluent 132 is passed to a separator 134, where it is combined with the dehydrocyclodimerization zone effluent
A hydrogen-rich stream 138 from separator 134 is recycled back to the reforming zone 130, and a third hydrogen-rich stream recycled to the dehydrocyclodimerization zone 230 as stream 140. From the separator 134, the liquid portion of the effluent is used within the hydrogen purification zone 350 as stream 356, where it is used to assist in removal of C3+ material from stream 144 in order to produce a purified hydrogen product stream 356 and an enriched liquid stream passed to the fractionation section 400. A liquid stream 352 from the fractionation section 400 may also be used within the hydrogen purification zone 350 and returned to the fractionation system as C3+ enriched stream 354. The fractionation section produces a light gas stream 404 rich in C1-C2 vapors, C3-C4 recycle stream 222 returned to the dehydrocyclodimerization section 230, and an aromatic-rich stream 150 produced for an aromatics recovery zone 300. The fractionation section 400 may have multiple separation vessels, each having multiple outlet streams comprising hydrogen, C1-C2 hydrocarbons, and C3-C4 hydrocarbons. These vessels may include but not limited to flash drums, condensers, reboilers, trayed or packed towers, distillation towers, absorbers, cryogenic loops, compressors, and combinations thereof.

The recycle stream containing C3-C4 hydrocarbons may be mixed with the feed 202 as discussed previously, but the recycle stream may also enter any or all of the reactors as well. For example, the recycle stream may also enter the second reactor 14, the third reactor 16, and the fourth reactor 18.

In yet another embodiment, the third light product separation zone outlet stream 140 containing C3+ aromatics is sent to the aromatic product separation zone, but a portion of the outlet stream 140 is also sent to the fourth reactor 18, or the third reactor 16 and the fourth reactor 18. Stream 140 containing C3+ aromatics can be further separated and having selective aromatics such as xylene, toluene or preferably benzene and toluene or most preferably benzene sent to the fourth reactor 18 or the third reactor 16 and fourth reactor 18. In one embodiment the third reactor 16 and the fourth reactor 18 might have three streams entering each reactor. Therefore the aromatic rich product stream 140 is combined with the light aliphatic hydrocarbon stream to feed the third and fourth reactors containing the third and fourth catalyst, respectively. In another embodiment no light aliphatic hydrocarbons are introduced to the third reactor 16 or the fourth reactor 18. In this embodiment, the alkylation of unconverted light aliphatic hydrocarbon with aromatics is maximized and the amount of unconverted hydrocarbons is minimized. Consequently, recycling the unconverted light aliphatic hydrocarbons is minimized or eliminated entirely. In this embodiment C5-C8 rich feed enters the first reactor 12 and C3-C4 rich feed enters the second reactor 14 or the second reactor 14 and the third reactor 16.

The reforming zone 130 may operate at a higher severity than usual. High severity means the temperature would be higher than the typical reforming zone operating temperature which is typically below 550°C. (1020°F). The only reason the reforming zone 130 may be able to perform at these higher temperatures without a significant decline in overall C5+ yield, is because the integration of dehydrocyclodimerization zone 230 will enable the conversion of the reforming process by-products generated in high severity operation. Traditionally, this high paraffin yield losses has disabled high severity operation of platforming units. By integrating dehydrocyclodimerization and platforming units, both higher selectivity and higher yield production of aromatics are achieved.

[0051] In this embodiment, the catalyst beds in the reforming zone 130 may comprise a reforming catalyst which typically contains one or more Group VIII noble metals (platinum, iridium, rhodium, and palladium) and a halogen such as chlorine and/or fluorine. The noble metals on the catalyst provide the function of increasing selectivity when converting of paraffins to aromatics by reducing catalytic cracking reactions. However by integrating the dehydrocyclodimerization and platforming units, it is now possible to utilize a lower cost non-noble metal catalyst while still achieving high yield production of aromatics. Generically, Niobium, Tungsten, Molybdenum, Vanadium and the mixture of thereof supported on SiO2, Al2O3, MgO, TiO2, ZrO2 and the mixture of thereof can be incorporated with supports that are alumina or non-Al2O3. These components of a catalyst are supported on a porous refractory carrier material such as alumina. The reforming catalyst may also contain one or more additional catalytic components such as rhenium, germanium, or tin. Further details on catalyst suitable for catalytic reforming may be obtained by reference to U.S. Pat. Nos. 3,740,328, 3,745,112, 3,948,804, and 4,367,137. Fixed bed or moving bed reactors may be used. The catalyst may, therefore, be present in the form of an extrudate or pellet. In contrast, the preferred physical form of the catalyst for use in a moving bed reaction and regeneration train is in the form of hard spherical particles having a diameter of from about 1/4 of an inch (0.0397 cm) to about 3/4 of an inch (0.397 cm). Reforming catalyst is available commercially from a number of suppliers, particularly UOP, LLC located in Des Plaines, Ill.

EXAMPLES

The examples listed in the following table are intended to further illustrate the subject embodiments. These illustrations of different embodiments are not meant to limit the claims to the particular details of these examples.

<table>
<thead>
<tr>
<th>Reforming Catalyst Type</th>
<th>Conventional</th>
<th>Integrated C3-CS DHCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5+ Yield, w %</td>
<td>87</td>
<td>83</td>
</tr>
<tr>
<td>p7 Conversion, %</td>
<td>80</td>
<td>95</td>
</tr>
<tr>
<td>Pressure, psig</td>
<td>68</td>
<td>68</td>
</tr>
<tr>
<td>Feedrate, % Base</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Aromatics, % Base</td>
<td>100%</td>
<td>102%</td>
</tr>
<tr>
<td>Production, % Base</td>
<td>137%</td>
<td>181%</td>
</tr>
</tbody>
</table>

The table demonstrates the benefits of the process claimed in this invention. The integration of dehydrocyclodimerization allows the integrated design to apply high severity reforming conditions such as higher pressure, higher temperature, and higher p7 conversion compared to traditional reforming without reducing aromatic yield performance. For example, the table shows that the integrated dehydrocyclodimerization design (DHCD) enables the use of higher temperature severities for a 37% increase in aromatics production within the same feedrate, or an 81%
increase with a 31% feedrate increase if higher pressures are leveraged to manage vapor flow constraints within the reformer reaction train.

[0054] It should be noted that various changes and modifications to the presently preferred embodiments described herein will be apparent to those skilled in the art. Such changes and modifications may be made without departing from the spirit and scope of the present subject matter and without diminishing its attendant advantages.

SPECIFIC EMBODIMENTS

[0055] A first embodiment of the invention is a hydrocarbon conversion process, comprising (a) passing a first hydrocarbon stream to reforming zone having a first non-noble metal catalyst wherein the reforming zone operates at reforming zone conditions to produce a reforming zone effluent stream; and (b) passing the reforming zone effluent stream to a dehydrocyclodimerization zone having a second catalyst wherein the dehydrocyclodimerization zone operates at dehydrocyclodimerization conditions to produce a dehydrocyclodimerization zone effluent. 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 first catalyst is a non-platinum containing 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 first non-noble metal catalyst comprises support alternatives to alumina for high acidic function activity. 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 a reforming zone comprises a high severity reactor train with reactor inlet temperatures above 550°C (1020°F). An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph, further comprising passing the dehydrocyclodimerization zone effluent to an aromatics recovery zone. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph, further comprising passing the reforming zone effluent to an aromatics recovery zone. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph, further comprising passing the reforming zone effluent and the dehydrocyclodimerization zone effluent to the same aromatics recovery zone. 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 dehydrocyclodimerization zone effluent is passed to a dehydrocyclodimerization light product separation zone and the reforming zone effluent is passed to a reforming light product separation zone. 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 first hydrocarbon stream comprises C5-C12 hydrocarbons. 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 first catalyst comprises an alumina and at least one active metal-containing component. 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 first catalyst comprises supported and unsupported mixed metal oxides. 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 first catalyst comprises supported molybdenum catalysts on supports selected from silica, zirconia, lithium-tantalum, niobia-modified gamma alumina, and chromium modified aluminas. 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 reforming zone conditions include a pressure of about 30 psia to about 200 psia. 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 reforming zone effluent stream comprises C5-C5 hydrocarbons and hydrogen. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph, further comprising passing a second hydrocarbon stream to the dehydrocyclodimerization zone. 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 second hydrocarbon stream comprises C3-C5 hydrocarbons. 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 dehydrocyclodimerization conditions include a temperature of about 350°C. to about 720°C. 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 dehydrocyclodimerization conditions include a pressure of about 0.1 psia to about 500 psia. 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 dehydrocyclodimerization zone effluent stream comprises H2, C1-6 hydrocarbons, and aromatics.

[0056] Without further elaboration, it is believed that using the preceding description that one skilled in the art can utilize the present invention to its fullest extent and easily ascertain the essential characteristics of this invention, without departing from the spirit and scope thereof, to make various changes and modifications of the invention and to adapt it to various usages and conditions. The preceding preferred specific embodiments are, therefore, to be construed merely illustrative, and not limiting the remainder of the disclosure in any way whatsoever, and that it is intended to cover various modifications and equivalent arrangements included within the scope of the appended claims.

[0057] In the foregoing, all temperatures are set forth in degrees Celsius and, all parts and percentages are by weight, unless otherwise indicated.

1. A hydrocarbon conversion process, comprising:
   (a) passing a first hydrocarbon stream to a reforming zone having a first non-noble metal catalyst wherein the reforming zone operates at reforming zone conditions to produce a reforming zone effluent stream; and
   (b) passing the reforming zone effluent stream to a dehydrocyclodimerization zone having a second catalyst wherein the dehydrocyclodimerization zone operates at dehydrocyclodimerization conditions to produce a dehydrocyclodimerization zone effluent.
2. The process of claim 1, wherein the first catalyst is a non-platinum containing catalyst.

3. The process of claim 1, wherein the first non-noble metal catalyst comprises support alternatives to alumina for high acidic function activity.

4. The process of claim 1, wherein a reforming zone comprises a high severity reactor train with reactor inlet temperatures above 550°F (1020°F).

5. The process of claim 1, further comprising passing the dehydrocyclodimerization zone effluent to an aromatics recovery zone.

6. The process of claim 1, further comprising passing the reforming zone effluent to an aromatics recovery zone.

7. The process of claim 1, further comprising passing the reforming zone effluent and the dehydrocyclodimerization zone effluent to the same aromatics recovery zone.

8. The process of claim 1, wherein the dehydrocyclodimerization zone effluent is passed to a dehydrocyclodimerization light product separation zone and the reforming zone effluent is passed to a reforming light product separation zone.

9. The process of claim 1, wherein the first hydrocarbon stream comprises C5-C12 hydrocarbons.

10. The process of claim 1, wherein the first catalyst comprises an alumina and at least one active metal-containing component.

11. The process of claim 1, wherein the first catalyst comprises supported and unsupported mixed metal oxides.

12. The process of claim 1, wherein the first catalyst comprises supported molybdenum catalysts on supports selected from silica, zirconia, lithium-tantalum, niobia-modified gamma alumina, and chromium modified aluminas.

13. The process of claim 1, wherein the reforming zone conditions include a pressure of about 30 psi to about 200 psi.

14. The process of claim 1, wherein the reforming zone effluent stream comprises C5-hydrocarbons and hydrogen.

15. The process of claim 1, further comprising passing a second hydrocarbon stream to the dehydrocyclodimerization zone.

16. The process of claim 9, wherein the second hydrocarbon stream comprises C3-C5 hydrocarbons.

17. The process of claim 1, wherein the second catalyst comprises a zeolite and at least one active metal-containing component.

18. The process of claim 1, wherein the dehydrocyclodimerization conditions include a temperature of about 350°C to about 720°C.

19. The process of claim 1, wherein the dehydrocyclodimerization conditions include a pressure of about 0.1 psi to about 500 psi.

20. The process of claim 1, wherein the dehydrocyclodimerization zone effluent stream comprises H2, C1-6 hydrocarbons, and aromatics.

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