

PROCESS FOR PRODUCING OLEFINS AND AROMATICS THROUGH HYDRO PYROLYSIS AND COKE MANAGEMENT

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority to U.S. Provisional Patent Application
5 Serial No. 63/109,507, filed November 4, 2020, the entire contents of which are hereby
incorporated by reference in their entirety.

BACKGROUND OF THE INVENTION

A. Field of the Invention

[0002] The invention generally concerns a hydropyrolysis process to produce olefins and
10 aromatics. The process can include (a) contacting a first hydrocarbon feed stream with a
catalyst and a hydrogen source under conditions sufficient to produce a used catalyst and an
intermediate stream comprising olefins and aromatics, and (b) contacting the used catalyst with
the intermediate stream and a coke precursor feed to produce a spent coked catalyst and a
15 products stream comprising additional olefins and aromatics. The spent coked catalyst can be
used to help with heat management of the reaction in step (a).

B. Description of Related Art

[0003] Light olefins such as ethylene, propylene, and butylene are important raw materials
for multiple end products like polymers, rubbers, plastics, octane booster compounds, etc. It is
expected that demand for light olefins will continue to grow. Aromatic hydrocarbons such as
20 benzene, toluene, and xylene, etc. are important commodity chemicals with continuously
increasing demand. High value chemicals such as light olefins and aromatics can be prepared
by fluidized catalytic cracking of petroleum based feed stocks.

[0004] Examples of fluidized catalytic cracking (FCC) processes are disclosed in U.S.
7,491,315, which uses a dual riser reactor configuration, and U.S. 9,550,708, which uses a
25 single riser reactor system. One of the issues facing current FCC processes is that the catalysts
used in such processes are prone to catalyst deactivation due to relatively rapid build-up of
carbonaceous deposits on the catalysts. In particular, carbonaceous deposits, i.e., coke
formation, can decrease catalyst efficiency and adversely impact light olefin and aromatics
yield.

SUMMARY OF THE INVENTION

[0005] A discovery has been made that provides a solution to at least some of the problems associated with fluidized catalytic cracking (FCC) processes that are used to make high value chemical such as olefins and/or aromatics. The solution is premised on catalytic cracking of a hydrocarbon with a fluidized catalyst in the presence of a hydrogen source (e.g., hydrogen (H₂) gas) to reduce coke formation on the catalyst and subsequently contacting the catalyst with a coke precursor to deposit coke on the catalyst. The use of hydrogen to reduce coke formation on the catalyst in a first reaction zone of a reactor (e.g., a riser reactor or downer reactor) can result in a larger catalyst/feed (C/F) ratio to supply endothermic heat of reaction on the reactor side when compared without using a hydrogen source. When coke precursor feed is added to the reactor at a downstream position to get the coke burnt in catalyst regenerator, the use of hydrogen source can keep the catalyst active in the first reaction zone. This can be beneficial in that the higher C/F ratio and/or the more active catalyst in the first reaction zone can result in higher yields of high value chemicals such as olefins and/or aromatics. Using a coke precursor in the second reaction zone can result in (1) cracking of the coke precursor, which can produce additional high value chemicals (e.g., olefins and/or aromatics) and/or (2) increasing the content of coke on the catalyst exiting the reactor and going to regenerator for coke burn. Regeneration of the coked catalyst can produce heat. Heat produced from (2) can be supplied to the first reaction zone, as desired. The amount of coke precursor used in the second reaction zone can be varied as desired and can be based on thermal energy needs of the first reaction zone. In other words there is a scope to have higher C/F ratio at lower coke precursor feed injection or maintain the same C/F ratio but with more active catalyst in the first reaction zone if coke on the catalyst exiting reactor is kept constant. Therefore, an advantage of the present invention can include increased olefin and/or aromatic production by managing the catalyst activity and/or an efficient heat management process during the FCC reaction.

[0006] One aspect of the present invention is directed to a process for producing olefins and aromatics. The process can include steps (a) and/or (b). In step (a) a first hydrocarbon feed stream containing a first hydrocarbon can be contacted with a cracking catalyst and a hydrogen source under conditions sufficient to produce an used catalyst and an intermediate stream containing olefins and aromatics. In step (b) the used catalyst and the intermediate stream can be contacted with a coke precursor stream to form a spent coked catalyst and a products stream containing additional olefins and aromatics. The coke precursor can contact with the used catalyst and can form carbonaceous deposits over a surface of the used catalyst to form the

spent coked catalyst. At least a portion of the olefins and the aromatics from the intermediate stream can be carried over to the products stream. In some aspects, the contacting condition in step (a) can include a temperature of 500 °C to 750 °C, or 600 °C to 750 °C. In some aspects, the contacting condition in step (a) can include a temperature of 700 °C to 850 °C. In some aspects, the contacting condition in step (a) can further include, a pressure of about 0.5 bara to about 5 bara, and/or contact time in a reactor of 0.1 s to 5 seconds. In some aspects, the catalyst to feed (C/F) ratio (w/w) in step (a) can be greater than the C/F ratio in step (b). In some aspects, the C/F ratio of step (a) can be 4 to 40. In some aspects, the C/F ratio of step (b) can be 4 to 40. In some aspects, the cracking catalyst can include a zeolite catalyst, a fluid catalytic cracking (FCC) catalyst, a hydrocracking catalyst, or aluminosilicates or any combinations thereof. Non-limiting examples of zeolite catalysts include ZSM-5, ZSM-11, ferrierite, heulandite, zeolite A, erionite, or chabazite, or any combinations thereof. In some aspects, the zeolite catalyst can be present in an active or inactive matrix. Non-limiting examples of a FCC catalyst include X-type zeolites, Y-type and/or USY-type zeolites, mordenite, faujasite, nano-crystalline zeolites, MCM mesoporous materials, SBA-15, a silico-alumino phosphate, a gallophosphate, a titanophosphate, spent or equilibrated catalyst from FCC units or any combinations thereof. In some aspects, the zeolites can be metal loaded zeolites. The FCC catalyst can be present in an active or inactive matrix with or without metal loading. Non-limiting examples of hydrocracking catalysts include metal oxide on a support with the metal sulfide being the active catalyst form. In some aspects, the support could be silica, alumina, carbon, titania, zirconia, or aluminosilicates or any combinations thereof. In some aspects, the cracking catalyst can be a zeolite and/or a metal loaded zeolite, such as zeolite and/or metal loaded zeolite embedded in a matrix. In some aspects, the cracking catalyst can be a ZSM-5 and/or a metal loaded ZSM-5. In some aspects, the olefins such as light olefins and aromatics yields per unit of coke formed in step (a) can be 4 to 20. The wt. % of coke in the used catalyst can be lower than the wt. % of coke in the spent coked catalyst. The spent coked catalyst can be regenerated and the regenerated catalyst can be recycled to step (a). The hydrogen source can be hydrogen (H₂) gas, methane, ethane, ethylene, propane, propylene, butanes, butenes or any combinations thereof, preferably H₂ gas. The first hydrocarbon feed stream can contain naphtha, condensates e.g. petroleum condensates, gas oils, C₃ and C₄ saturated gas, cracked naphtha stream, recycled crackable hydrocarbon stream containing C₃ and C₄ saturated gas or any combinations thereof, and the first hydrocarbon can be one or more hydrocarbons comprised in naphtha, condensates e.g. petroleum condensates, gas oils, C₃ and C₄ saturated gas, cracked naphtha stream, recycled crackable hydrocarbon stream containing C₃ and C₄ saturated gas or any combinations thereof.

The coke precursor stream can include fluid catalytic cracking cycle oils and slurry oils, coker streams, slurry oil, crude oil, carbon black oil, cracked distillates, vacuum residue, or cracked oils e.g. cracked oils from sources like bio oils or fuel oil, or any combination thereof. In some aspects, a second hydrocarbon feed stream containing a second hydrocarbon can be provided to step (a) and the cracking catalyst can be contacted with the first hydrocarbon feed stream and the second hydrocarbon feed stream to produce the intermediate stream and the used catalyst. In some aspects, the cracking catalyst can be contacted with the first hydrocarbon feed stream and the second hydrocarbon feed stream in presence of the hydrogen source to produce the intermediate stream. In some aspects, the cracking catalyst can be contacted with the second hydrocarbon feed stream downstream to contacting the cracking catalyst with the first hydrocarbon feed stream. The second hydrocarbon feed stream can contain crude oil; atmospheric residue; vacuum gas oils; unconverted oil from hydrocrackers e.g. hydrocracker bottoms; hydrowax; plastics or polymers dissolved or slurried in solvents; polyolefin oligomers; plastics; partially depolymerized plastics; plastic pyrolysis oil; hydrogenated plastic pyrolysis oil; recycled naphtha and gas oil streams; naphtha; gas oils; vacuum gas oil and/or unconverted oil products from hydrocracking of plastics; or any combination thereof, and the second hydrocarbon can be one or more hydrocarbons comprised in crude oil; atmospheric residue; vacuum gas oils; unconverted oil from hydrocrackers e.g. hydrocracker bottoms; hydrowax; plastics or polymers dissolved or slurried in solvents; polyolefin oligomers; plastics; partially depolymerized plastics; plastic pyrolysis oil; hydrogenated plastic pyrolysis oil; recycled naphtha and gas oil streams; naphtha; gas oils; vacuum gas oil and/or unconverted oil products from hydrocracking of plastics; or any combination thereof. Plastics can include but are not limited to polyolefins (HDPE, LDPE, LLDPE, PP), PS, PVC, PVDC, PET or combinations thereof. The plastics can be virgin, post-consumer recycled or post-industrial recycled plastics. In some aspects, the average molecular weight of the one or more second hydrocarbons e.g. hydrocarbons in the second hydrocarbon feed stream can be higher than the average molecular weight of the one or more first hydrocarbons e.g. hydrocarbons in the first hydrocarbon feed stream.

[0007] In some aspects, a third hydrocarbon feed stream containing a third hydrocarbon can be provided to step (a) and the cracking catalyst can be contacted with the first hydrocarbon feed stream, the second hydrocarbon feed stream, and the third hydrocarbon feed stream to produce the intermediate stream and used catalyst. In some aspects, the cracking catalyst can be contacted with the first hydrocarbon feed stream, the second hydrocarbon feed stream, and

the third hydrocarbon feed stream in presence of the hydrogen source to produce the intermediate stream. In some aspects, the cracking catalyst can be contacted with the third hydrocarbon feed stream downstream to contacting the cracking catalyst with the second hydrocarbon feed stream and the first hydrocarbon feed stream. The third hydrocarbon feed stream can contain crude oil, atmospheric residue, vacuum gas oils, unconverted oil from hydrocrackers e.g. hydrocracker bottoms, hydrowax, polyolefin oligomers, plastics, partially depolymerized plastics, plastics or polymers dissolved or slurried in solvents, plastic pyrolysis oil, hydrogenated plastic pyrolysis oil, heavy recycled crackable hydrocarbon stream, gas oils, vacuum gas oil and unconverted oil products from hydrocracking of plastics, or any combinations thereof, and the third hydrocarbon can be one or more hydrocarbons comprised in crude oil, atmospheric residue, vacuum gas oils, unconverted oil from hydrocrackers e.g. hydrocracker bottoms, hydrowax, polyolefin oligomers, plastics, partially depolymerized plastics, plastics or polymers dissolved or slurried in solvents, plastic pyrolysis oil, hydrogenated plastic pyrolysis oil, heavy recycled crackable hydrocarbon stream, gas oils, vacuum gas oil and unconverted oil products from hydrocracking of plastics, or any combinations thereof. In some aspects, the average molecular weight of the one or more third hydrocarbons e.g. hydrocarbons in the third hydrocarbon feed stream can be higher than the average molecular weight of the one or more second hydrocarbons e.g. hydrocarbons in the second hydrocarbon feed stream. The first, second and/or third hydrocarbons stream optionally contain catalysts which are suspended, dispersed, and/or dissolved in the respective streams.

[0008] In some aspects, the spent coked catalyst can be comprised in the products stream and the process can include separating the spent coked catalyst from the products stream. In some aspects, the spent coked catalyst can be separated from the products stream with a cyclone separator. In some aspects, the products stream after separation from the spent coked catalyst, can be sent to a fractionator/separation train known in the prior art to obtain purified gaseous olefins and/or aromatics. The gaseous olefins can be ethylene, propylene, and/or butylene. The aromatics can be benzene, toluene, ethylbenzene and/or xylene. In some aspects, the separated spent coked catalyst can be regenerated. In some aspects, the regeneration process can include contacting the separated spent coked catalyst with a regeneration stream. In some aspects, the regeneration stream can contain oxygen (O₂). In some aspects, the regeneration stream can contain 18 vol. % to 30 vol. % or 20 vol. % to 25 vol. % of oxygen (O₂). In some aspects, the regeneration stream can contain air, diluted air, oxygen enriched air or any combination thereof. In some aspects, the regeneration stream can be contacted with the spent coked catalyst at a

temperature 500 °C to 800 °C, a pressure of 0.5 bara to 5 bara, and/or contact time of 5 min to 30 min. In some aspects, the regeneration of the catalyst from the spent coked catalyst can produce heat and at least a portion of the heat can be provided to step (a). In some aspects, the regenerated catalyst can be recycled to step (a).

5 [0009] In some aspects, steps (a) and (b) of the hydropyrolysis process can be performed in a reactor comprising a first reaction zone and a second reaction zone, and wherein step (a) is performed in the first reaction zone and step (b) is performed in the second reaction zone. The reaction zones can be in fluid communication with each other. In some aspects, the reactor can be a riser unit or a downer unit of a fluid catalytic cracking unit. In one aspect, the first and
10 second reaction zones are comprised in a riser unit of a fluid catalytic cracking unit, wherein the first reaction zone is upstream of the second reaction zone, and wherein the first and second reaction zones are in fluid communication with one another. In another aspect, the first and second reaction zones are comprised in a downer unit of a fluid catalytic cracking unit, wherein the first reaction zone is upstream of the second reaction zone, and wherein the first and second
15 reaction zones are in fluid communication with one another. The average hydrocarbon residence time in the reactor can be 100 ms to 2 sec, preferably 100 ms to 1 sec. The hydrogen source can be provided to step (a) comprised in a lift stream and the lift stream can further comprise steam. In some aspects, the lift stream can contain 0.1 wt. % to 99.9 wt. % of the hydrogen source such as H₂ and 0.1 wt. % to 99.9 wt. % of steam. In some aspects, the lift
20 stream can contain hydrocarbon gases. In some particular aspects, the lift stream can contain 1 wt. % of hydrogen with optionally the balance being steam and hydrocarbon gases. The lift stream can be used to aid flow of materials such as catalysts such as cracking catalyst, used catalyst, spent coked catalyst, and/or hydrocarbons such as first, second and/or third hydrocarbons, cracked products such as olefins and/or aromatics in the reactor and for
25 controlling average hydrocarbon residence time in the reactor as well as for improved contacting and mixing of catalyst with hydrocarbon streams. In some aspects, the flow rate of the lift stream can be increased to decrease average hydrocarbon residence time in the reactor.

[0010] In certain aspects, an oxygenate can be fed to the reactor at one or more positions. The oxygenate can be provided to step (a) and/or step (b). In some aspects, one or more
30 oxygenate streams comprising the oxygenate can be fed to the reactor. The one or more oxygenate streams can be fed to the reactor at one or more positions. In some aspects, multiple oxygenate streams such as 2 to 15, or 2 to 10 oxygenate streams, can be provided to multiple positions of the reactor. The one or more oxygenate streams can be provided to step (a) and/or

step (b). In certain aspects, the oxygenate can be fed to the reactor comprised with the first hydrocarbon feed stream, second hydrocarbon feed stream, third hydrocarbon feed stream and/or coke precursor stream. In some aspects, the oxygenate streams can be fed to the reactor through nozzles. In some aspects, the amount of oxygenate provided to the first reaction zone (e.g. high conversion zone) can be higher than that to the second reaction zone (e.g. low conversion zone). In some aspects, the number of oxygenate streams provided to the first reaction zone can be higher than the number of oxygenate streams provided to the second reaction zone, e.g. the number of oxygenate stream nozzles can be higher in the first reaction zone than the number of oxygenate streams nozzles in the second reaction zone. Introduction of higher amount of oxygenates to the high conversion zone can help in maintaining high temperature severity in the high conversion zone and as a result increased formation of light gas olefins. In the reactor the oxygenate can be cracked to produce heat and increase reactor temperature, and/or decrease coke wt. % on the cracking catalyst and/or used catalyst. The oxygenate can be used to control temperature e.g. local temperature of the reactor at one or more position along the length of the reactor. In certain aspects, the process can include controlling local temperature of the reactor at the one or more positions where the oxygenate is fed by measuring the local temperature at one or more positions where the oxygenate is fed, and increasing the oxygenate flow rate to the reactor if the local temperature at the one or more positions is lower than a desired temperature at the one or more positions or decreasing the oxygenate flow rate to the reactor if the local temperature at the one or more positions is higher than a desired temperature at the one or more positions. In some aspects, the local temperature at the one or more positions can be measured by one or more temperature sensors positioned near and/or at the one or more positions and on a wall of the reactor. A heat profile of the reactor can be established by controlling local temperature of the reactor at the one or more positions. In some aspects, the oxygenate feed can be methanol. In certain aspects, the reactor can include one or more temperature sensors positioned on an inner surface of a reactor wall along a length of the reactor with corresponding one or more first heaters positioned on the outer surface of the reactor wall layer. The reactor local temperature during the hydropyrolysis process can be controlled with the one or more heat sensors, the one or more heaters and/or by feeding oxygenate to the one or more positions of the reactor, such that a difference between a temperature at an inlet for the cracking catalyst to the reactor and a temperature at an outlet for the spent coked catalyst from the reactor can be less than 200°C, preferably less than 150 °C more preferably less than 100 °C. This enables operating the reactor at a desired higher temperature severity levels and also in applying a temperature profile along the reactor length

for desired product yields. It also helps in partially decoupling the reactor from the regenerator from a heat balance perspective and enables operations at higher catalyst flowrate, if desired. In some aspects, the one or more first heaters can form a first heater layer of the reactor and the reactor can further include a first insulation layer positioned on an outer surface of the first heater layer, insulating the first heater layer from outside. The reactor can further include one or more second heaters positioned on an outer surface of the first insulation layer. The first insulation layer and the one or more second heaters helps minimizing the heat loss from the reactor. In some aspects, an average inner diameter of the reactor at the first reaction zone is higher than an average inner diameter of the reactor at the second reaction zone. In some other aspects, average inner diameter of the reactor at the first reaction zone is lower than an average inner diameter of the reactor at the second reaction zone. In some aspects, the residence time in the reactor can be 0.1 to 1 sec so as to have high light gas olefins selectivity and reducing secondary cracking to aromatics. In some aspects, the residence time in the reactor can be controlled to 0.1 to 1 sec by reducing reactor length. In some aspects, high value chemicals (e.g. gaseous olefins, benzene, toluene, xylene and/or ethyl benzene), or at least a portion of the high value chemicals can be separated from the products stream and the residual stream can be fed back to the bottom of the reactor. In some aspects, the reactor can be operated at higher superficial velocity for low residence time. Operation at higher temperature severity such as in the high conversion zone helps in increasing the conversion and in making more light olefins. In some aspects, increasing the superficial velocity, reducing the reactor length and/or separation of high value chemicals from the products stream can avoid further formation of aromatics from the formed light olefins.

[0011] In some aspects the features and benefits as disclosed above can be extended to a dual reactor concept. In some aspects, the high value chemicals e.g. gaseous olefins, benzene, toluene, xylene and ethyl benzene, or at least a portion of the high value chemicals can be separated from the products stream and the residual stream can be fed to a second reactor. The residual stream can contain crackable hydrocarbons. The residual stream can be processed in the second reactor to form additional methane, gaseous olefins and/or aromatics. In some aspects, the residual stream can be cracked in second reactor. The residence time in the reactor and second reactor can be controlled independently to 0.1 to 1 sec by reducing the length of the reactor and/or the second reactor so as to have high light gas olefins selectivity and reducing secondary cracking to aromatics. In some aspects, the reactor and the second reactor can be operated at higher superficial velocity for low residence time. Operation at higher temperature

severity such as in the high conversion zone helps in increasing the conversion and making more light gas olefins. In some aspects, increasing the superficial velocity, reducing the reactor length and/or separation of high value chemicals from the products stream can avoid further formation of aromatics from the formed light olefins. The two reactor configuration can offer increased flexibility to tune the cracking zone operating parameters. In some aspects, the reactor and the second reactor can receive regenerated catalyst from the regenerator, and the spent catalyst from the reactor and the second reactor can be sent to the regenerator for regeneration. In some aspects, the reactor can receive regenerated catalyst from the regenerator, catalyst from the reactor outlet can be fed to the second reactor, and the spent catalyst from the second reactor can be sent to the regenerator for regeneration.

[0012] One aspect of the present invention is directed to a system for producing olefins and aromatics. The system can include the reactor and/or the regeneration unit of the present invention. In some aspects, the system can include the second reactor.

[0013] The following includes definitions of various terms and phrases used throughout this specification.

[0014] The term “atmospheric residue” as used herein refers to a distillation bottom stream obtained from a crude oil atmospheric distillation column. The term “vacuum residue” as used herein refers to a distillation bottom stream obtained from a crude oil vacuum distillation column. Vacuum residue refers to a hydrocarbon fraction having a boiling point of greater than about 550 °C.

[0015] Terms “Light olefins”, “gaseous olefins” and “light gas olefins” are used interchangeably herein and refer to ethylene, propylene, and butylene.

[0016] The terms “about” or “approximately” are defined as being close to as understood by one of ordinary skill in the art. In one non-limiting embodiment, the terms are defined to be within 10%, preferably within 5%, more preferably within 1%, and most preferably within 0.5%.

[0017] The terms “wt. %,” “vol. %,” or “mol. %” refers to a weight percentage of a component, a volume percentage of a component, or molar percentage of a component, respectively, based on the total weight, the total volume of material, or total moles, that includes the component. In a non-limiting example, 10 grams of component in 100 grams of the material is 10 wt.% of component.

[0018] The term “substantially” and its variations are defined to include ranges within 10%, within 5%, within 1%, or within 0.5%.

[0019] The terms “inhibiting” or “reducing” or “preventing” or “avoiding” or any variation of these terms, when used in the claims and/or the specification includes any measurable
5 decrease or complete inhibition to achieve a desired result.

[0020] The term “effective,” as that term is used in the specification and/or claims, means adequate to accomplish a desired, expected, or intended result.

[0021] The use of the words “a” or “an” when used in conjunction with any of the terms “comprising,” “including,” “containing,” or “having” in the claims, or the specification, may
10 mean “one,” but it is also consistent with the meaning of “one or more,” “at least one,” and “one or more than one.”

[0022] The phrase “and/or” can include “and” or “or.” To illustrate, A, B, and/or C can include: A alone, B alone, C alone, a combination of A and B, a combination of A and C, a combination of B and C, or a combination of A, B, and C.

[0023] The words “comprising” (and any form of comprising, such as “comprise” and “comprises”), “having” (and any form of having, such as “have” and “has”), “including” (and any form of including, such as “includes” and “include”) or “containing” (and any form of containing, such as “contains” and “contain”) are inclusive or open-ended and do not exclude
15 additional, unrecited elements or method steps.

[0024] The methods of the present invention can “comprise,” “consist essentially of,” or “consist of” particular ingredients, components, compositions, *etc.* disclosed throughout the specification. With respect to the transitional phrase “consisting essentially of,” in one non-limiting aspect, a basic and novel characteristic of the methods of the present invention are their abilities to produce olefins and aromatics by hydropyrolysis of hydrocarbons in presence
20 of a fluidized catalyst and a hydrogen source such as H₂, and subsequently forming a coked catalyst by contacting the catalyst with a coke precursor.

[0025] Other objects, features and advantages of the present invention will become apparent from the following figures, detailed description, and examples. It should be understood, however, that the figures, detailed description, and examples, while indicating specific
30 embodiments of the invention, are given by way of illustration only and are not meant to be limiting. Additionally, it is contemplated that changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed

description. In further embodiments, features from specific embodiments may be combined with features from other embodiments. For example, features from one embodiment may be combined with features from any of the other embodiments. In further embodiments, additional features may be added to the specific embodiments described herein.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0026] Advantages of the present invention may become apparent to those skilled in the art with the benefit of the following detailed description and upon reference to the accompanying drawings.

10 [0027] FIG. 1 is a schematic of an example of the present invention to produce olefins and aromatics.

[0028] FIG. 2 is a schematic of a second example of the present invention to produce olefins and aromatics.

[0029] FIG. 3 is a schematic of a third example of the present invention to produce olefins and aromatics.

15 [0030] FIG. 4A is a schematic of a fourth example of the present invention to produce olefins and aromatics.

[0031] FIG. 4B is a top cross-sectional view of reactor 402.

[0032] FIG. 5 is a schematic of a fifth example of the present invention to produce olefins and aromatics.

20 [0033] FIG. 6 is a schematic of a sixth example of the present invention to produce olefins and aromatics.

[0034] FIG. 7 is a schematic of an example of the present invention to produce olefins and aromatics, wherein the system of FIG. 1- 6 contains an optional second reactor.

25 [0035] FIG. 8 total aromatic and light olefins yield per unit of coke for hydropyrolysis and high severity pyrolysis of plastic feed.

[0036] While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings. The drawings may not be to scale.

DETAILED DESCRIPTION OF THE INVENTION

[0037] A discovery has been made that provides a solution to at least some of the aforementioned problems associated with producing olefins and aromatics by a FCC process. The solution can include performing hydropyrolysis of a hydrocarbon feed with a fluidized catalyst in the presence of a hydrogen source to produce olefins such as light olefins and aromatics and subsequently contacting the catalyst with a coke precursor to form a coked catalyst. It was discovered in the context of the present invention that using a hydrogen source during fluidized catalytic cracking can reduce coke formation on the catalyst during cracking and can also increase light olefin and aromatics yield. The heat balance of the process can be maintained by forming coke deposits on the catalyst by contacting catalyst with a coke precursor. The hydropyrolysis process with a fluidized catalyst can be performed in a high reactive zone of a FCC cracking unit, such as a bottom portion of a riser unit or a top portion of a downer unit and the coke formation on the fluidized catalyst can be performed in a downstream low reactive zone of a FCC cracking unit, such as a top portion of a riser unit or a bottom portion of a downer unit.

[0038] These and other non-limiting aspects of the present invention are discussed in further detail in the following sections with reference to the figures. The units shown in the figures can include one or more heating and/or cooling devices (e.g., insulation, electrical heaters, jacketed heat exchangers in the wall) or controllers (e.g., computers, flow valves, automated values, etc.) that can be used to control temperatures and pressures of the processes. While only one unit is usually shown, it should be understood that multiple units can be housed in one unit.

[0039] Referring to FIG. 1, systems and methods for producing olefins and/or aromatics according to one example of the present invention is described. The system 100 can include a cracking unit 102. The cracking unit can contain a high reactive zone 102a and a low reactive zone 102b. The low reactive zone 102b can be positioned downstream to the high reactive zone 102a. The zones 102a and 102b can be in fluid communication. The boundary 103 between the zones can be an operational not physical boundary and can change position depending on the conditions such as operational conditions and/or reaction conditions in the cracking unit 102. The average temperature in the high reactive zone 102a can be higher than that in the low reactive zone 102b. A lift stream 106 containing a hydrogen source can be fed to the cracking unit 102 at the high reactive zone 102a. A catalyst stream 108 containing a cracking catalyst e.g. fluidized catalyst can be fed to the cracking unit 102 at the high reactive zone 102a. In

some aspects, the lift stream 106 and the catalyst stream 108 can be fed to the cracking unit 102 as separate feeds and can be combined in the cracking unit 102 to form a combined stream. The cracking catalyst can be fluidized in the combined stream. The overall flow direction of the catalyst along with the combined stream in the cracking unit 102 is shown with the dotted arrow. In some aspects, the lift stream 106 and the catalyst stream 108 can be combined and fed to the cracking unit as a combined stream (not shown). A first hydrocarbon feed stream 110 containing a first hydrocarbon can be fed to the cracking unit 102 at the high reactive zone 102a downstream to the lift stream 106, and the catalyst stream 108. A second hydrocarbon feed stream 118 containing a second hydrocarbon can be fed to the cracking unit 102 at the high reactive zone 102a, downstream to the lift stream 106, the catalyst stream 108, and the first hydrocarbon feed stream 110. A third hydrocarbon feed stream 119 containing a third hydrocarbon can be fed to the cracking unit 102 at the high reactive zone 102a downstream to the lift stream 106, the catalyst stream 108, the first hydrocarbon feed stream 110, and the second hydrocarbon feed stream 118. In the cracking unit 102 the first hydrocarbon feed stream 110, the second hydrocarbon feed stream 118, and/or the third hydrocarbon feed stream 119 can be contacted with the fluidized cracking catalyst in the combined stream to form an used catalyst and an intermediate stream containing olefins and/or aromatics. The olefins and/or aromatics can be formed by hydropyrolysis of at least a portion of the first, second, and/or third hydrocarbon. The overall flow direction of the used catalyst along with the intermediate stream in the cracking unit 102 is shown with the dotted arrow. A coke precursor stream 112 containing a coke precursor can be fed to the cracking unit 102 at the low reactive zone 102b. The coke precursor, used catalyst and the intermediate stream can be contacted to form a spent coked catalyst and additional olefins and/or aromatics. Coke can get deposited on the used catalyst, by the contact of the coke precursor and used catalyst, to form the spent coked catalyst from the used catalyst. The spent coked catalyst can be separated from the olefins and/or aromatics. A products stream 114 containing at least a portion of the additional olefins and/or aromatics, and the olefins and/or aromatics from the intermediate stream can exit the cracking unit 102. A stream 116 containing the spent coke catalyst can exit the cracking unit 102. In some aspects, the spent coked catalyst can be separated from the olefins and/or aromatics in a disengagement device such as a volute followed by a further stripping of hydrocarbons from spent coked catalyst in a stripping vessel equipped with steam stripping coils and baffles for efficient stripping of hydrocarbons from spent coked catalyst. In some aspects, an oxygenate stream 120 containing an oxygenate can be fed to the cracking unit 102. In some aspects, the oxygenated stream 120 can be fed to the cracking unit 102 through a nozzle. In some aspects,

the oxygenate stream 120 can be fed to the cracking unit 102 at zone 102a, downstream to the lift stream 106, the catalyst stream 108, the first hydrocarbon feed stream 110, and the second hydrocarbon feed stream 118, and upstream to third hydrocarbon feed stream 119. In some aspects, the oxygenate stream 120 can be fed to the cracking unit 102 at zone 102a downstream to the lift stream 106, the catalyst stream 108, and the first hydrocarbon feed stream 110, and upstream to the second hydrocarbon feed stream 118 and third hydrocarbon feed stream 119 (not shown). In some aspects, the oxygenate stream 120 can be fed to the cracking unit 102 at zone 102b (not shown). In some aspects, multiple oxygenate streams can be fed to the cracking unit 102 at zone 102a and/or 102b at multiple positions (not shown). The products stream 114 can be sent to a fractionation unit and a downstream separation train to further purify the olefins and/or aromatics (not shown). The stream 116 can be sent to a regeneration unit (not shown). In some aspects, an average inner diameter of the cracking unit 102 at zone 102a can be higher than the average inner diameter at zone 102b (not shown). In some aspects, an average inner diameter of the cracking unit 102 at zone 102b can be higher than the average inner diameter at zone 102a (not shown).

[0040] Referring to FIG. 2, systems and methods for producing olefins and/or aromatics according to a second example of the present invention is described. The system 200 can include a cracking unit 202. The cracking unit can contain a high reactive zone 202a and a low reactive zone 202b. The low reactive zone 202b can be positioned downstream to the high reactive zone 202a. The zones 202a and 202b can be in fluid communication. The boundary 203 between the zones can be an operational not physical boundary and can change position depending on the conditions such as operational conditions and/or reaction conditions in the cracking unit 202. The average temperature in the high reactive zone 202a can be higher than that in the low reactive zone 202b. A lift stream 206 containing a hydrogen source can be fed to the cracking unit 202 at the high reactive zone 202a. A catalyst stream 208 containing a cracking catalyst e.g. fluidized catalyst can be fed to the cracking unit 202 at the high reactive zone 202a. In some aspects, the lift stream 206 and the catalyst stream 208 can be fed to the cracking unit 202 as separate feeds and can be combined in the cracking unit 202 to form a combined stream. The cracking catalyst can be fluidized in the combined stream. The overall flow direction of the catalyst along with the combined stream in the cracking unit 202 is shown with the dotted arrow. A first hydrocarbon feed stream 210 containing a first hydrocarbon can be fed to the cracking unit 202 at the high reactive zone 202a downstream to the lift stream 206, and the catalyst stream 208. A second hydrocarbon feed stream 218 containing a second

hydrocarbon can be fed to the cracking unit 202 at the high reactive zone 202a downstream to the lift stream 206, the catalyst stream 208, and the first hydrocarbon feed stream 210. A third hydrocarbon feed stream 219 containing a third hydrocarbon can be fed to the cracking unit 202 at the high reactive zone 202a downstream to the lift stream 206, the catalyst stream 208, the first hydrocarbon feed stream 210, and the second hydrocarbon feed stream 218. In the cracking unit 202 the first hydrocarbon feed stream 210, the second hydrocarbon feed stream 218, and/or the third hydrocarbon feed stream 219 can be contacted with the fluidized catalyst in the combined stream to form an used catalyst and an intermediate stream containing olefins and/or aromatics. The olefins and/or aromatics can be formed by hydropyrolysis of at least a portion of the first, second, and/or third hydrocarbon. The overall flow direction of the used catalyst along with the intermediate stream in the cracking unit 202 is shown with the dotted arrow. A coke precursor stream 212 containing a coke precursor can be fed to the cracking unit 202 at the low reactive zone 202b. The coke precursor, used catalyst and the intermediate stream can be contacted to form a spent coked catalyst and additional olefins and/or aromatics. Coke can get deposited on the used catalyst, by the contact of the coke precursor and used catalyst, to form the spent coked catalyst from the used catalyst. The spent coked catalyst can be separated from the olefins and/or aromatics. A products stream 214 containing at least a portion of the additional olefins and/or aromatics, and the olefins and/or aromatics from the intermediate stream can exit the cracking unit 202. A stream 216 containing the spent coke catalyst can exit the cracking unit 202. In some aspects, the spent coked catalyst can be separated from the olefins and/or aromatics in a disengagement device such as a volute followed by a further stripping of hydrocarbons from spent coked catalyst in a stripping vessel equipped with steam stripping coils and baffles for efficient stripping of hydrocarbons from spent coked catalyst. In some aspects, oxygenate streams 220a/b/c/d can be fed to the cracking unit 202. In some aspects, the oxygenated streams 220a/b/c/d can be fed to the cracking unit 202 through nozzles 231a/b/c/d respectively. The oxygenate streams can contain an oxygenate. Oxygenate stream 220a can be fed to zone 202a downstream to first hydrocarbon stream 210, upstream to second hydrocarbon stream 218. Oxygenate stream 220b can be fed to zone 202a downstream to second hydrocarbon stream 218, upstream to third hydrocarbon stream 219. Oxygenate stream 220c can be fed to zone 202a downstream to third hydrocarbon stream 219. Oxygenate stream 220d can be fed to zone 202b upstream to coke precursor stream 212. In some aspects, multiple oxygenate streams can be fed to the cracking unit 202 at zone 202a and/or 202b at multiple positions. The products stream 214 can be sent to a fractionation unit and a downstream separation train to further purify the olefins and/or aromatics (not shown).

The stream 216 can be sent to a regeneration unit (not shown). The average inner diameter of the cracking unit 202 at zone 202a can be higher than the average inner diameter at zone 202b. Under similar process conditions, the average hydrocarbon residence time in such a reactor e.g. 202, can be lower compared to that in a reactor having similar or same average inner diameter at the upstream high reactive zone and the downstream low reactive zone, and olefin selectivity over aromatics selectivity from hydrocracking can be increased with such reactor design e.g. of reactor 202.

[0041] Referring to FIG. 3, systems and methods for producing olefins and/or aromatics according to a third example of the present invention is described. The system 300 can include a cracking unit 302. The cracking unit can contain a high reactive zone 302a and a low reactive zone 302b. The low reactive zone 302b can be positioned downstream to the high reactive zone 302a. The zones 302a and 302b can be in fluid communication. The boundary 303 between the zones can be an operational not physical boundary and can change position depending on the conditions such as operational conditions and/or reaction conditions in the cracking unit 302. The average temperature in the high reactive zone 302a can be higher than that in the low reactive zone 302b. A lift stream 306 containing a hydrogen source can be fed to the cracking unit 302 at the high reactive zone 302a. A catalyst stream 308 containing a cracking catalyst e.g. fluidized catalyst can be fed to the cracking unit 302 at the high reactive zone 302a. In some aspects, the lift stream 306 and the catalyst stream 308 can be fed to the cracking unit 302 as separate feeds and can be combined in the cracking unit 302 to form a combined stream. The cracking catalyst can be fluidized in the combined stream. The overall flow direction of the catalyst along with the combined stream in the cracking unit 302 is shown with the dotted arrow. A first hydrocarbon feed stream 310 containing a first hydrocarbon can be fed to the cracking unit 302 at the high reactive zone 302a downstream to the lift stream 306, and the catalyst stream 308. A second hydrocarbon feed stream 318 containing a second hydrocarbon can be fed to the cracking unit 302 at the high reactive zone 302a downstream to the lift stream 306, the catalyst stream 308, and the first hydrocarbon feed stream 310. A third hydrocarbon feed stream 319 containing a third hydrocarbon can be fed to the cracking unit 302 at the high reactive zone 302a downstream to the lift stream 306, the catalyst stream 308, the first hydrocarbon feed stream 310, and the second hydrocarbon feed stream 318. In the cracking unit 302 the first hydrocarbon feed stream 310, the second hydrocarbon feed stream 318, and/or the third hydrocarbon feed stream 319 can be contacted with the fluidized catalyst in the combined stream to form an used catalyst and an intermediate stream containing olefins and/or

aromatics. The olefins and/or aromatics can be formed by hydrolysis of at least a portion of the first, second, and/or third hydrocarbon. The overall flow direction of the used catalyst along with the intermediate stream in the cracking unit 302 is shown with the dotted arrow. A coke precursor stream 312 containing a coke precursor can be fed to the cracking unit 302 at the low reactive zone 302b. The coke precursor can be contacted with the used catalyst to form a spent coked catalyst and additional olefins and/or aromatics. Coke can get deposited on the used catalyst, by the contact of the coke precursor and used catalyst, to form the spent coked catalyst from the used catalyst. The spent coked catalyst can be separated from the olefins and/or aromatics. A products stream 314 containing at least a portion of the additional olefins and/or aromatics, and the olefins and/or aromatics from the intermediate stream can exit the cracking unit 302. A stream 316 containing the spent coke catalyst can exit the cracking unit 302. In some aspects, the spent coked catalyst can be separated from the olefins and/or aromatics in a disengagement device such as a volute followed by a further stripping of hydrocarbons from spent coked catalyst in a stripping vessel equipped with steam stripping coils and baffles for efficient stripping of hydrocarbons from spent coked catalyst. In some aspects, oxygenate streams 320a/b/c/d can be fed to the cracking unit 302. In some aspects, the oxygenated streams 320a/b/c/d can be fed to the cracking unit 302 through nozzles 331a/b/c/d respectively. The oxygenate streams can contain an oxygenate. Oxygenate stream 320a can be fed to zone 302a downstream to first hydrocarbon stream 310, upstream to second hydrocarbon stream 318. Oxygenate stream 320b can be fed to zone 302a downstream to second hydrocarbon stream 318, upstream to third hydrocarbon stream 319. Oxygenate stream 320c can be fed to zone 302a downstream to third hydrocarbon stream 319. Oxygenate stream 320d can be fed to zone 302b upstream to coke precursor stream 312. In some aspects, multiple oxygenate streams can be fed to the cracking unit 302 at zone 302a and/or 302b at multiple positions. The products stream 314 can be sent to a fractionation unit and a downstream separation to further purify the olefins and/or aromatics (not shown). The stream 316 can be sent to a regeneration unit (not shown). The average inner diameter of the cracking unit 302 at zone 302b can be higher than the average inner diameter at zone 302a. Under similar process conditions, the average hydrocarbon residence time in such a reactor e.g. 302, can be higher compared to that of a reactor having similar or same average inner diameter at the upstream high reactive zone and the downstream low reactive zone, and aromatics selectivity over olefins selectivity from hydrocracking can be increased with such reactor design e.g. of reactor 302.

[0042] Referring to FIGS. 4A and 4B, systems and methods for producing olefins and/or aromatics according to a fourth example of the present invention is described. The system 400 can include a cracking unit 402. The cracking unit can contain a high reactive zone 402a and a low reactive zone 402b. The low reactive zone 402b can be positioned downstream to the high reactive zone 402a. The zones 402a and 402b can be in fluid communication. The boundary 403 between the zones can be an operational not physical boundary and can change position depending on the conditions such as operational conditions and/or reaction conditions in the cracking unit 402. The average temperature in the high reactive zone 402a can be higher than that in the low reactive zone 402b. The reactor 402 can contain one or more first heater(s) positioned along a wall 421 along the length of the reactor 402. The one or more first heater(s) can form a first heater layer 422. The reactor 402 can contain an insulation layer 424 positioned along an outer surface of the first heater layer 422. The reactor 402 can further contain one or more second heater(s) positioned along an outer surface of the insulation layer 424, forming a second heater layer 426. The reactor 402 can contain a second insulation layer 430 positioned along an outer surface of the second heater layer 426. The reactor 402 can further contain one or more temperature sensors 428 positioned on the wall 421, configured to measure temperature of the reactor. A top cross sectional view of reactor 402 is shown in FIG. 4B. The wall 421, first heater layer 422, insulation layer 424 and the second heater layer 426 and the second insulation layer 430 can surround the bore of the reactor 402. A lift stream 406 containing a hydrogen source can be fed to the cracking unit 402 at the high reactive zone 402a. A catalyst stream 408 containing a cracking catalyst e.g. fluidized catalyst can be fed to the cracking unit 402 at the high reactive zone 402a. In some aspects, the lift stream 406 and the catalyst stream 408 can be fed to the cracking unit 402 as separate feeds and can be combined in the cracking unit 402 to form a combined stream. The catalyst can be fluidized in the combined stream. The overall flow direction of the catalyst along with the combined stream in the cracking unit 402 is shown with the dotted arrow. A first hydrocarbon feed stream 410 containing a first hydrocarbon can be fed to the cracking unit 402 at the high reactive zone 402a downstream to the lift stream 406, and the catalyst stream 408. A second hydrocarbon feed stream 418 containing a second hydrocarbon can be fed to the cracking unit 402 at the high reactive zone 402a downstream to the lift stream 406, the catalyst stream 408, and the first hydrocarbon feed stream 410. A third hydrocarbon feed stream 419 containing a third hydrocarbon can be fed to the cracking unit 402 at the high reactive zone 402a downstream to the lift stream 406, the catalyst stream 408, the first hydrocarbon feed stream 410, and the second hydrocarbon feed stream 418. In the cracking unit 402 the first hydrocarbon feed stream

410, the second hydrocarbon feed stream 418, and/or the third hydrocarbon feed stream 419 can be contacted with the fluidized catalyst in the combined stream to form an used catalyst and an intermediate stream containing olefins and/or aromatics. The olefins and/or aromatics can be formed by hydropyrolysis of at least a portion of the first, second, and/or third hydrocarbon. The overall flow direction of the used catalyst along with the intermediate stream in the cracking unit 402 is shown with the dotted arrow. A coke precursor stream 412 containing a coke precursor can be fed to the cracking unit 402 at the low reactive zone 402b. The coke precursor, used catalyst, and the intermediate stream can be contacted to form a spent coked catalyst and additional olefins and/or aromatics. Coke can get deposited on the used catalyst, by the contact of the coke precursor and used catalyst, to form the spent coked catalyst from the used catalyst. The spent coked catalyst can be separated from the olefins and/or aromatics. A products stream 414 containing at least a portion of the additional olefins and/or aromatics, and the olefins and/or aromatics from the intermediate stream can exit the cracking unit 402. A stream 416 containing the spent coke catalyst can exit the cracking unit 402. In some aspects, the spent coked catalyst can be separated from the olefins and/or aromatics in a disengagement device such as a volute followed by a further stripping of hydrocarbons from spent coked catalyst in a stripping vessel equipped with steam stripping coils and baffles for efficient stripping of hydrocarbons from spent coked catalyst. In some aspects, an oxygenate stream 420 containing an oxygenate can be fed to the cracking unit 402. In some aspects, the oxygenate stream 420 can be fed to the cracking unit 402 through a nozzle. In some aspects, the oxygenate stream 420 can be fed to the cracking unit 402 at zone 402a, downstream to the lift stream 406, the catalyst stream 408, the first hydrocarbon feed stream 410, and the second hydrocarbon feed stream 418, and upstream to third hydrocarbon feed stream 419. In some aspects, the oxygenate stream 420 can be fed to the cracking unit 402 at zone 402a downstream to the lift stream 406, the catalyst stream 408, and the first hydrocarbon feed stream 410, and upstream to the second hydrocarbon feed stream 418, and third hydrocarbon feed stream 419 (not shown). In some aspects, the oxygenate stream 420 can be fed to the cracking unit 402 at zone 402b (not shown). In some aspects, multiple oxygenate streams can be fed to the cracking unit 402 at zone 402a and/or 402b at multiple positions (not shown). The products stream 414 can be sent to a fractionation unit to further purify the olefins and/or aromatics (not shown). The stream 416 can be sent to a regeneration unit (not shown). In some aspects, an average inner diameter of the cracking unit 402 at zone 402a can be higher than the average inner diameter at zone 402b (not shown). In some aspects, an average inner diameter of the cracking unit 402 at zone 402b can be higher than the average inner diameter at zone 402a (not shown).

[0043] Referring to FIG. 5, systems and methods for producing olefins and/or aromatics according to a fifth example of the present invention is described. The system 500 can include a riser 502 and a regeneration unit 530. The riser 502 can contain a high reactive zone 502a and a low reactive zone 502b. The low reactive zone 502b can be positioned downstream e.g. above the high reactive zone 502a. The zones 502a and 502b can be in fluid communication. The boundary 503 between the zones can be an operational not physical boundary and can change position depending on the conditions such as operational conditions and/or reaction conditions in the riser 502. The average temperature in the high reactive zone 502a can be higher than that in the low reactive zone 502b. A lift stream 506 containing a hydrogen source can be fed to the riser 502 at the high reactive zone 502a from a bottom portion of the riser. The lift stream 506 can aid upward flow of materials in the riser. A catalyst stream 508 containing a cracking catalyst e.g. fluidized catalyst can be fed to the riser 502 at the high reactive zone 502a. In some aspects, the lift stream 506 and the catalyst stream 508 can be fed to the riser 502 as separate feeds and can be combined in the riser 502 to form a combined stream. The catalyst can be fluidized in the combined stream. In some aspects, the lift stream 506 and the catalyst stream 508 can be combined and fed to the cracking unit as a combined stream (not shown). A first hydrocarbon feed stream 510 containing a first hydrocarbon can be fed to the cracking unit 502 at the high reactive zone 502a downstream to the lift stream 506, and the catalyst stream 508. A second hydrocarbon feed stream 518 containing a second hydrocarbon can be fed to the riser 502 at the high reactive zone 502a downstream to the lift stream 506, the catalyst stream 508, and the first hydrocarbon feed stream 510. A third hydrocarbon feed stream 519 containing a third hydrocarbon can be fed to the riser 502 at the high reactive zone 502a downstream to the lift stream 506, the catalyst stream 508, the first hydrocarbon feed stream 510, and the second hydrocarbon feed stream 518. In the riser 502 the first hydrocarbon feed stream 510, the second hydrocarbon feed stream 518, and/or the third hydrocarbon feed stream 519 can be contacted with the fluidized catalyst in the combined stream to form an used catalyst and an intermediate stream containing olefins and/or aromatics. The olefins and/or aromatics can be formed by hydropyrolysis of at least a portion of the first, second, and/or third hydrocarbon. A coke precursor stream 512 containing a coke precursor can be fed to the riser 502 at the low reactive zone 502b. The coke precursor, used catalyst, and the intermediate stream can be contacted to form a spent coked catalyst and additional olefins and/or aromatics. Coke can get deposited on the used catalyst, by the contact of the coke precursor and used catalyst, to form the spent coked catalyst from the used catalyst. The spent coked catalyst can be separated from the olefins and/or aromatics. A products stream 514

containing at least a portion of the additional olefins and/or aromatics, and the olefins and/or aromatics from the intermediate stream can exit the riser 502 from a top portion of the riser. A stream 516 containing the spent coke catalyst can exit the riser 502. In some aspects, the spent coked catalyst can be separated from the olefins and/or aromatics in a disengagement device
5 such as a volute followed by a further stripping of hydrocarbons from spent coked catalyst in a stripping vessel equipped with steam stripping coils and baffles for efficient stripping of hydrocarbons from spent coked catalyst. In some aspects, an oxygenate stream 520 containing an oxygenate can be fed to the riser 502. In some aspects, the oxygenate stream 520 can be fed to the riser 502 through a nozzle. In some aspects, the oxygenate stream 520 can be fed to the
10 riser 502 at zone 502a, downstream to the lift stream 506, the catalyst stream 508, the first hydrocarbon feed stream 510, and the second hydrocarbon feed stream 518, and upstream to third hydrocarbon feed stream 519. In some aspects, the oxygenate stream 520 can be fed to the riser 502 at zone 502a downstream to the lift stream 506, the catalyst stream 508, and the first hydrocarbon feed stream 510, and upstream to the second hydrocarbon feed stream 518,
15 and third hydrocarbon feed stream 519 (not shown). In some aspects, the oxygenate stream 520 can be fed to the riser 502 at zone 502b (not shown). In some aspects, multiple oxygenate streams can be fed to the riser 502 at zone 502a and/or 502b at multiple positions (not shown). In some aspects, the riser 502 can contain one or more heater(s), one or more temperature sensor(s) and/or insulation layer as described in system 400 (FIG. 4 A and B) (not shown). In
20 some aspects, an average inner diameter of the riser 502 at zone 502a can be higher than the average inner diameter at zone 502b (not shown). In some aspects, an average inner diameter of the riser 502 at zone 502b can be higher than the average inner diameter at zone 502a (not shown). The products stream 514 can be sent to a fractionation unit to further purify the olefins and/or aromatics (not shown). The stream 516 can be sent to the regeneration unit 530. A
25 regeneration stream 532 containing oxygen (O_2) can be fed to the regeneration unit 530. In the regeneration unit 530 the regeneration stream 532 can be contacted with the spent coked catalyst and can regenerate the cracking catalyst from the spent coked catalyst. The regenerated cracking catalyst from the regeneration unit 530 can be recycled to the riser 502 via stream 508. An effluent stream 534 containing carbon oxides resulting from the catalyst regeneration
30 process by the regeneration stream, can exit the regeneration unit 530. In some aspects, the effluent stream 534 can be sent to a CO boiler unit (not shown).

[0044] Referring to FIG. 6, systems and methods for producing olefins and/or aromatics according to a sixth example of the present invention is described. The system 600 can include

a downer 602 and regeneration unit 630. The downer 602 can contain a high reactive zone 602a and a low reactive zone 602b. The low reactive zone 602b can be positioned downstream e.g. below the high reactive zone 602a. The zones 602a and 602b can be in fluid communication. The boundary 603 between the zones can be an operational not physical boundary and can change position depending on the conditions such as operational conditions and/or reaction conditions in the downer 602. The average temperature in the high reactive zone 602a can be higher than that in the low reactive zone 602b. A lift stream 606 containing a hydrogen source can be fed to the downer 602 at the high reactive zone 602a from a top portion of the downer 602. The lift stream 606 can aid downward flow of materials in the downer 602. A catalyst stream 608 containing a cracking catalyst e.g. fluidized catalyst can be fed to the downer 602 at the high reactive zone 602a. In some aspects, the lift stream 606 and the catalyst stream 608 can be fed to the downer 602 as separate feeds and can be combined in the downer 602 to form a combined stream. The catalyst can be fluidized in the combined stream. In some aspects, the lift stream 606 and the catalyst stream 608 can be combined and fed to the cracking unit as a combined stream (not shown). A first hydrocarbon feed stream 610 containing a first hydrocarbon can be fed to the cracking unit 602 at the high reactive zone 602a downstream to the lift stream 606, and the catalyst stream 608. A second hydrocarbon feed stream 618 containing a second hydrocarbon can be fed to the downer 602 at the high reactive zone 602a downstream to the lift stream 606, the catalyst stream 608, and the first hydrocarbon feed stream 610. A third hydrocarbon feed stream 619 containing a third hydrocarbon can be fed to the downer 602 at the high reactive zone 602a downstream to the lift stream 606, the catalyst stream 608, the first hydrocarbon feed stream 610, and the second hydrocarbon feed stream 618. In the downer 602 the first hydrocarbon feed stream 610, the second hydrocarbon feed stream 618, and/or the third hydrocarbon feed stream 619 can be contacted with the fluidized catalyst in the combined stream to form an used catalyst and an intermediate stream containing olefins and/or aromatics. The olefins and/or aromatics can be formed by hydropyrolysis of at least a portion of the first, second, and/or third hydrocarbon. A coke precursor stream 612 containing a coke precursor can be fed to the downer 602 at the low reactive zone 602b. The coke precursor, the used catalyst and the intermediate stream can be contacted to form a spent coked catalyst and additional olefins and/or aromatics. Coke can get deposited on the used catalyst, by the contact of the coke precursor and used catalyst, to form the spent coked catalyst from the used catalyst. The spent coked catalyst can be separated from the olefins and/or aromatics. A products stream 614 containing at least a portion of the additional olefins and/or aromatics, and the olefins and/or aromatics from the intermediate stream can exit the downer

602 from a bottom portion of the riser. A stream 616 containing the spent coke catalyst can exit the downer 602. In some aspects, the spent coked catalyst can be separated from the olefins and/or aromatics in a disengagement device followed by a further stripping of hydrocarbons from spent coked catalyst. In some aspects, an oxygenate stream 620 containing an oxygenate

5 can be fed to the downer 602. In some aspects, the oxygenate stream 620 can be fed to the downer 602 through a nozzle. In some aspects, the oxygenate stream 620 can be fed to the downer 602 at zone 602a, downstream to the lift stream 606, the catalyst stream 608, the first hydrocarbon feed stream 610, the second hydrocarbon feed stream 618, and the third hydrocarbon feed stream 619. In some aspects, the oxygenate stream 620 can be fed to the

10 downer 602 at zone 602a downstream to the lift stream 606, the catalyst stream 608, and the first hydrocarbon feed stream 610, and upstream to the second hydrocarbon feed stream 618, and third hydrocarbon feed stream 619 (not shown). In some aspects, the oxygenate stream 620 can be fed to the downer 602 at zone 602b (not shown). In some aspects, multiple oxygenate streams can be fed to the downer 602 at zone 602a and/or 602b at multiple positions (not

15 shown). In some aspects, the downer 602 can contain one or more heater(s), one or more temperature sensor(s) and/or insulator layer as described in system 400 (FIG. 4 A and B) (not shown). In some aspects, an average inner diameter of the downer 602 at zone 602a can be higher than the average inner diameter at zone 602b (not shown). In some aspects, an average inner diameter of the downer 602 at zone 602b can be higher than the average inner diameter

20 at zone 602a (not shown). The products stream 614 can be sent to a fractionation unit and a downstream separation train to further purify the olefins and/or aromatics (not shown). The stream 616 can be sent to the regeneration unit 630. A regeneration stream 632 containing oxygen (O₂) can be fed to the regeneration unit 630. In the regeneration unit 630 the regeneration stream 632 can be contacted with the spent coked catalyst and can regenerate the

25 cracking catalyst from the spent coked catalyst. The regenerated cracking catalyst from the regeneration unit 630 can be recycled to the downer 602 via stream 608. An effluent stream 634 containing carbon oxides resulting from the catalyst regeneration process by the regeneration stream, can exit the regeneration unit 630. In some aspects, the effluent stream 634 can be sent to a CO boiler unit (not shown).

30 **[0045]** Referring to FIG. 7 in certain aspects, the system 100, 200, 300, 400, 500, or 600 independently can further contain an optional second reactor 702. The high value chemicals (e.g. gaseous olefins, benzene, toluene, xylene and/or ethyl benzene), or at least a portion of the high value chemical can be separated from the products stream (114, 214, 314, 414, 514,

or 614 respectively) in a separator 704 to form a high value chemical stream 714 and a residual stream 706. The stream 714 can be further purified to produce purified ethene, propene, butene, benzene, toluene, xylene and/or ethyl benzene. The residual stream 706 can contain crackable hydrocarbon and can be fed to the optional second reactor 702. A 708 stream containing catalyst can be fed to the reactor 702. In some aspects, the stream 708 can contain the regenerated catalyst from a regenerator. In some aspects, the regenerator can be the same regenerator (e.g. 530, 630 for system 500, 600 respectively) from which regenerated catalyst (e.g. through streams 108, 208, 308, 408, 508, 608 respectively) is fed to the reactor (102, 202, 302, 402, 502, or 602 respectively). In some aspects, the stream 708 can contain catalyst from the stream 116, 216, 316, 416, 516, or 616 respectively, from the reactor 102, 202, 302, 402, 502, or 602 respectively, effluent. In the second reactor 702 the residual stream (e.g. hydrocarbons in the residual stream) can be cracked to produce additional methane, gaseous olefins and/or aromatics. A stream 710 containing the additional methane, gaseous olefins and/or aromatics can exit the reactor. The stream 710 can be further purified to produce purified methane, gaseous olefins and/or aromatics. A stream 716 containing spent catalyst can exit the second reactor 702 and can be sent to a regenerator. In some aspects, the regenerator can be the same regenerator (e.g. 530, 630 for system 500, or 600 respectively) from which regenerated catalyst (e.g. through streams 108, 208, 308, 408, 508, or 608 respectively) is fed to the reactor 102, 202, 302, 402, 502, or 602 respectively. The residual stream 706 can be processed in the second reactor 702 to form additional methane, gaseous olefins and/or aromatics. In some aspects, the residual stream 706 (e.g. hydrocarbons in the residual stream) can be cracked in the second reactor 702. The residence time in the second reactor 702 can be controlled to 0.1 to 1 sec. The two reactor configuration can offer increased flexibility to tune the cracking zone operating parameters.

[0046] In the high reactive zone 102a, 202a, 302a, 402a, 502a, 602a, olefins and aromatics can be formed by cracking of the first, second and/or third hydrocarbon, by the contact of the first, second and/or third hydrocarbon with the cracking catalyst in a hydrolysis mode, and the used catalyst can be formed from the cracking catalyst. The hydrogen source in the high reactive zone can reduce coke formed on the cracking catalyst and/or used catalyst. The contacting condition of the first, second and/or third hydrocarbon and the cracking catalyst in the high reactive zone 102a, 202a, 302a, 402a, 502a, 602a can include a temperature of 500 °C to 750 °C, or 600 °C to 850 °C, or 600 °C to 750 °C, or 700 °C to 850 °C, or at least any one of, equal to any one of, or between any two of 500, 525, 550, 575, 600, 625, 650, 675, 700,

725, 750, 775, 800, 825 and 850°C. An increase in the contacting temperature in the high reactive zone 102a, 202a, 302a, 402a, 502a, 602a can result in a higher yield of ethylene over propylene (e.g. higher ethylene to propylene product ratio) by the cracking process. In some aspects, the contacting condition can further include (i) a pressure of 0.5 bara to 5 bara or at least any one of, equal to any one of, or between any two of 0.5, 1, 2, 3, 4, and 5 bara, and/or (ii) a contact time of 0.1 sec to 5 sec or at least any one of, equal to any one of, or between any two of 0.1, 0.3, 0.5, 0.7, 0.9, 1, 2, 3, 4, 5 sec in the reactor.

[0047] In the low reactive zone 102b, 202b, 302b, 402b, 502b, 602b, the spent coked catalyst can be formed from the used catalyst, by the contact of the coke precursor and the used catalyst. The coke precursor can deposit coke on the used catalyst to form the spent coked catalyst. The contacting condition of the coke precursor and the used catalyst in the low reactive zone 102b, 202b, 302b, 402b, 502b, 602b can include i) a temperature of 500 °C to 850 °C or at least any one of, equal to any one of, or between any two of 500, 525, 550, 575, 600, 650, 675, 700, 725, 750, 775, 800, 825 and 850°C, ii) a pressure of 0.5 bara to 5 bara or at least any one of, equal to any one of, or between any two of 0.5, 1, 2, 3, 4, and 5 bara, and/or iii) contact time of 0.1 to 5 sec or at least any one of, equal to any one of, or between any two of 0.1, 0.3, 0.5, 0.7, 0.9, 1, 2, 3, 4, 5 sec. The spent coked catalyst can contain 0.1 wt. % to 10 wt. % or at least any one of, equal to any one of, or between any two of 0.1, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 wt. % of coke. The catalyst to feed (w/w) ratio in the high reactive zone 102a, 202a, 302a, 402a, 502a, 602a can be higher than the catalyst to feed (w/w) ratio in the low reactive zone 102b, 202b, 302b, 402b, 502b, 602b.

[0048] The lift stream 106, 206, 306, 406, 506, 606 can contain a hydrogen source. In some aspects, the hydrogen source can be hydrogen (H₂) gas. In some aspects, the lift stream 106, 206, 306, 406, 506, 606 can contain 0.1 vol. % to 99 vol. % or at least any one of, equal to any one of, or between any two of 0.1, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, 50, 60, 70, 80, 90, 99, 99.5, and 99.9 vol. % of the hydrogen source such as hydrogen (H₂) gas and 0.1 vol. % to 99.9 vol. % or at least any one of, equal to any one of, or between any two of 0.1, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, 50, 60, 70, 80, 90, 99, 99.5, and 99.9 vol. % of steam. In some particular aspects, the lift stream 106, 206, 306, 406, 506, 606 can further contain 0 vol. % to 35 vol. % or at least any one of, equal to any one of, or between any two of 0, 0.1, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, and 35 vol. % of methane, 0 vol. % to 25 vol. % or at least any one of, equal to any one of, or between any two of 0, 0.1, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, and 25 vol. % of ethane and , 0 vol. % to 25 vol. % or at least any one of, equal to any one of, or

between any two of 0, 0.1, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, and 25 vol. % of ethylene. The lift stream 106, 206, 306, 406, 506, 606 can aid material flow in the reactors 102, 202, 302, 402, 502, 602 and can be used for controlling residence time such as average hydrocarbon residence time in the reactor 102, 202, 302, 402, 502, 602 as well as for improved contacting and mixing of catalyst with hydrocarbon streams..

[0049] The catalyst stream 108, 208, 308, 408, 508, 608 can contain a fluidized cracking catalyst. The cracking catalyst can contain a zeolite catalyst, a fluid catalytic cracking (FCC) catalyst, a hydrocracking catalyst, aluminosilicates or any combination thereof. Non-limiting examples of zeolite catalysts include ZSM-5, ZSM-11, ferrierite, heulandite, zeolite A, erionite, and chabazite, or any combination thereof. In some aspects, the zeolite catalyst can be present in an active or inactive matrix. Non-limiting examples of a FCC catalyst include X-type zeolites, Y-type and/or USY-type zeolites, mordenite, faujasite, nano-crystalline zeolites, MCM mesoporous materials, SBA-15, a silico-alumino phosphate, a gallophosphate, a titanophosphate, spent or equilibrated catalyst from FCC units or any combination thereof. Zeolites mentioned herein can be metal loaded zeolites. The FCC catalyst can be present in an active or inactive matrix with or without metal loading. Non-limiting examples of hydrocracking catalysts include metal oxide on a support with the metal sulfide being the active catalyst form. In some aspects, the support could be silica, alumina, carbon, titania, zirconia, aluminosilicates. In some aspects, the cracking catalyst can be a zeolite and/or a metal loaded zeolite. The zeolite and/or a metal loaded zeolite can be embedded in a matrix. In some aspects, the cracking catalyst can be a ZSM-5 and/or a metal loaded ZSM-5.

[0050] The first hydrocarbon feed stream 110, 210, 310, 410, 510, 610 can contain naphtha, condensates e.g. petroleum condensates, gas oils, C₃ and C₄ saturated gas, cracked naphtha stream, recycled crackable hydrocarbon stream containing C₃ and C₄ saturated gas and/or and recycled gas and low molecular weight liquids from the process (e.g. recovered from 114, 214, 314, 414, 514, 614 respectively) the first hydrocarbon can be one or more hydrocarbons comprised in naphtha, condensates e.g. petroleum condensates, gas oils, cracked naphtha stream, C₃ saturated gases, C₄ saturated gases, and/or recycled gas and low molecular weight liquids from the process. In some aspects, the naphtha can be straight run or cracked naphtha. In certain aspects, the first hydrocarbon feed stream 110, 210, 310, 410, 510, 610 can further contain an oxygenate such as methanol. In some aspects, the first hydrocarbon feed stream 110, 210, 310, 410, 510, 610 can contain 0 vol. % to 20 vol. % or at least any one of, equal to any one of, or between any two of 0, 0.1, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, and 20 vol. % of an

oxygenate such as methanol. The oxygenate can get cracked in the reactor to produce heat and reduce coke in the cracking catalyst and/or used catalyst. In some aspects, the first hydrocarbon feed stream 110, 210, 310, 410, 510, 610 can be preheated to a desired temperature level and fed to the cracking unit.

5 **[0051]** The second hydrocarbon feed stream 118, 218, 318, 418, 518, 618 can contain crude oil; atmospheric residue; vacuum gas oils; unconverted oil from hydrocrackers e.g. hydrocracker bottoms; hydrowax; plastics or polymers dissolved or slurried in solvents; polyolefin oligomers; plastics; partially depolymerized plastics; plastic pyrolysis oil; hydrogenated plastic pyrolysis oil; recycled naphtha and gas oil streams; naphtha; gas oils;
10 vacuum gas oil and/or unconverted oil products from hydrocracking of plastics; or recycled heavier crackable hydrocarbon liquids from the process (e.g. recovered from 114, 214, 314, 414, 514, 614 respectively) or any combinations thereof, and the second hydrocarbon can be one or more hydrocarbons comprised in crude oil; atmospheric residue; vacuum gas oils; unconverted oil from hydrocrackers e.g. hydrocracker bottoms; hydrowax; plastics or polymers
15 dissolved or slurried in solvents; polyolefin oligomers; plastics; partially depolymerized plastics; plastic pyrolysis oil; hydrogenated plastic pyrolysis oil; recycled naphtha and gas oil streams; naphtha; gas oils; vacuum gas oil and/or unconverted oil products from hydrocracking of plastics; or recycled heavier crackable hydrocarbon liquids from the process (e.g. recovered from 114, 214, 314, 414, 514, 614 respectively) or any combinations thereof. In certain aspects,
20 the second hydrocarbon feed stream 118, 218, 318, 418, 518, 618 can further contain an oxygenate such as methanol. In some aspects, the second hydrocarbon feed stream 118, 218, 318, 418, 518, 618 can contain 0 vol. % to 20 vol. % or 0, 0.1, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, and 20 vol. % of an oxygenate such as methanol. The oxygenate can get cracked in the reactor to produce heat and reduce coke in the cracking catalyst and/or used catalyst. In some
25 aspects, the second hydrocarbon feed stream 118, 218, 318, 418, 518, 618 can be preheated to a desired temperature level and fed to the cracking unit.

[0052] The third hydrocarbon feed stream 119, 219, 319, 419, 519, 619 can contain crude oil; atmospheric residue; vacuum gas oils; unconverted oil from hydrocrackers e.g. hydrocracker bottoms; hydrowax; polyolefin oligomers; plastics; partially depolymerized
30 plastics; plastics or polymers dissolved or slurried in solvents; plastic pyrolysis oil; hydrogenated plastic pyrolysis oil; heavy recycled crackable hydrocarbon stream; gas oils; vacuum gas oil; unconverted oil products from hydrocracking of plastics; recycled heavy liquids from the process (e.g. recovered from 114, 214, 314, 414, 514, 614 respectively) or

products from hydrocracking of plastics; or any combination thereof, and the third hydrocarbon can be one or more hydrocarbons comprised in crude oil; atmospheric residue; vacuum gas oils; unconverted oil from hydrocrackers e.g. hydrocracker bottoms; hydrowax; polyolefin oligomers; plastics; partially depolymerized plastics; plastics or polymers dissolved or slurried in solvents; plastic pyrolysis oil; hydrogenated plastic pyrolysis oil; heavy recycled crackable hydrocarbon stream; gas oils; vacuum gas oil; unconverted oil products from hydrocracking of plastics; recycled heavy liquids from the process (e.g. recovered from 114, 214, 314, 414, 514, 614 respectively) or products from hydrocracking of plastics; or any combinations thereof. In certain aspects, the third hydrocarbon feed stream 119, 219, 319, 419, 519, 619 can further contain an oxygenate such as methanol. In some aspects, the third hydrocarbon feed stream 119, 219, 319, 419, 519, 619 can contain 0 vol. % to 20 vol. % or at least any one of, equal to any one of, or between any two of 0, 0.1, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, and 20 vol. % of an oxygenate such as methanol. The oxygenate can get cracked in the reactor to produce heat and reduce coke in the cracking catalyst and/or used catalyst. In some aspects, the third hydrocarbon feed stream 119, 219, 319, 419, 519, 619 can be preheated to a desired temperature level and fed to the cracking unit.

[0053] The oxygenate stream 120, 220a, 220b, 220c, 220d, 320a, 320b, 320c, 320d, 420, 520, 620 can contain an oxygenate. In some aspects, the oxygenate can be methanol. The oxygenate can get cracked in the reactor 102, 202, 302, 402, 502, 602 to produce heat. The heat produced can reduce a temperature drop in the reactor 102, 202, 302, 402, 502, 602 during the hydropyrolysis process. Introduction of oxygenates to the reactor 102, 202, 302, 402, 502, 602 can result in reduced temperature drop from inlet of 106, 206, 306, 406, 506, 606 to outlet of 114, 214, 314, 414, 514, 614 compared to when an oxygenate is not introduced. Reducing the temperature drop can increase the yields of olefins and/or aromatics produced by cracking in the reactor 102, 202, 302, 402, 502, 602. In some aspects, the oxygenate flow rate to the reactor can be controlled to control local temperature of reactor at the position(s) where the oxygenate is fed, and for establishing a temperature profile in the reactor. Also when used in combination with the feed through feed introduction nozzle, the oxygenate has a beneficial effect of atomizing the feed to smaller droplets and also resulting in lower coke deposition on the catalyst.

[0054] The coke precursor stream 112, 212, 312, 412, 512, 612 can contain a coke precursor. In some aspects, the coke precursor can be fluid catalytic cracking cycle oils and slurry oils, coker streams, slurry oil, crude oil, carbon black oil, cracked distillates, vacuum residue, or

cracked oils e.g. cracked oils from sources like bio oils or fuel oil, or any combination thereof. In some aspects, the coke precursor stream 112, 212, 312, 412, 512, 612 can further contain steam. In some aspects, the coke precursor stream can contain 40 vol. % to 100 vol. % or at least any one of, equal to any one of, or between any two 40, 50, 60, 70, 80, 90, and 100 vol. % of coke precursor and 0 vol. % to 60 vol. % or at least any one of, equal to any one of, or between any two 0, 10, 20, 30, 40, 50, and 60 vol. % steam.

[0055] The products stream 114, 214, 314, 414, 514, 614 can contain light olefins and aromatics. In some aspects, the light olefins can be ethylene, propylene, or butylene or any combination thereof. In some aspects, the aromatics can be benzene, toluene, xylene, or ethyl benzene or any combination thereof.

[0056] In the regeneration unit 530, 630 the regeneration stream 532, 632 and the spent coked catalyst stream 516, 616 can be contacted at (i) a temperature of 500 to 850 °C or at least any one of, equal to any one of, or between any two of 500, 525, 550, 575, 600, 625, 650, 675, 700, 725, 750, 775, 800, 825 and 850°C, (ii) a pressure of 0.5 bara to 5 bara or at least any one of, equal to any one of, or between any two of 0.5, 1, 2, 3, 4, and 5 bara, or (iii) a contact time of 5 min to 30 min or at least any one of, equal to any one of, or between any two of 5, 10, 15, 20, 25 and 30 min, or any combination thereof to regenerate the cracking catalyst. In some aspects, the regeneration stream 532, 632 can contain 18 vol. % to 30 vol. % or 20 vol. % to 25 vol. % O₂. The regeneration process can produce heat and at least a portion of the heat can be provided to the reactor 102, 202, 302, 402, 502, 602. In some aspects, the regeneration stream can contain air, diluted air, and/or oxygen enriched air. In some aspects, in the regenerator, an optional provision for fuel gas or heavy hydrocarbon burning can be provided for maintaining the regenerator temperature to support the reactions in the reactors.

[0057] Although embodiments of the present application and their advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the embodiments as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the above disclosure, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein can be utilized. Accordingly, the appended

claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

[0058] In the context of the present invention, at least the following 36 aspects are described. Aspect 1 is directed to a hydropyrolysis process to produce higher yields of olefins and aromatics, the process comprising: (a) contacting a first hydrocarbon feed stream comprising a first hydrocarbon with a cracking catalyst and a hydrogen source under conditions sufficient to produce a used catalyst and an intermediate stream comprising olefins and aromatics; and (b) contacting the used catalyst and the intermediate stream with a coke precursor stream to produce a spent coked catalyst and a products stream comprising additional olefins and aromatics. Aspect 2 is directed to the hydropyrolysis process of aspect 1, wherein a catalyst to feed (C/F) ratio in step (a) is greater than the C/F ratio in step (b). Aspect 3 is directed to the hydropyrolysis process of aspects 1 or 2, wherein the wt. % of coke in the used catalyst is lower than the wt. % of coke in the spent coked catalyst. Aspect 4 is directed to the hydropyrolysis process of any one of aspects 1 to 3, wherein the process further comprises regenerating the spent coked catalyst. Aspect 5 is directed to the hydropyrolysis process of aspect 4, wherein the regenerated catalyst is recycled to step (a). Aspect 6 is directed to the hydropyrolysis process of any one of aspects 1 to 5, wherein the hydrogen source is hydrogen (H₂) gas, methane, ethane, ethylene, propane, propylene, butanes, butenes or any combinations thereof. Aspect 7 is directed to the hydropyrolysis process of any one of aspects 1 to 6, wherein the contacting condition in step (a) comprises a temperature of 500 °C to 750 °C. Aspect 8 is directed to the hydropyrolysis process of any one of aspects 1 to 6, wherein the contacting condition in step (a) comprises a temperature of 700 °C to 850 °C. Aspect 9 is directed to the hydropyrolysis process of any one of aspects 1 to 8, wherein the first hydrocarbon feed stream comprises naphtha, condensates, gas oils, C₃ and C₄ saturated gas, cracked naphtha stream, recycled crackable hydrocarbon stream comprising C₃ and C₄ saturated gas or any combinations thereof. Aspect 10 is directed to the hydropyrolysis process of any one of aspects 1 to 9, wherein the coke precursor stream comprises cycle oils, coker streams, crude oil, slurry oil, carbon black oil, cracked distillates, cracked oils, vacuum residue or any combination thereof. Aspect 11 is directed to the hydropyrolysis process of any one of aspects 1 to 10, further comprising providing a second hydrocarbon feed stream comprising a second hydrocarbon to step (a), and the intermediate stream is produced by contacting the catalyst with the first hydrocarbon feed stream and the second hydrocarbon feed stream, wherein the average molecular weight of the second hydrocarbon feed stream is higher than the average molecular

weight of the first hydrocarbon feed stream. Aspect 12 is directed to the hydropyrolysis process of aspect 11, wherein the second hydrocarbon feed stream comprises crude oil, atmospheric residue, vacuum gas oils, unconverted oil from hydrocrackers, hydrowax, polyolefin oligomers, plastics or polymers dissolved or slurried in solvents, plastics, partially depolymerized plastics, plastic pyrolysis oil, hydrogenated plastic pyrolysis oil, recycled naphtha and gas oil streams, naphtha, gas oils, vacuum gas oil and unconverted oil products from hydrocracking of plastics or any combinations thereof. Aspect 13 is directed to the hydropyrolysis process of aspect 11 or 12, wherein the second hydrocarbon feed stream is contacted with the catalyst downstream to contacting the catalyst with the first hydrocarbon feed stream. Aspect 14 is directed to the hydropyrolysis process of any one of aspects 11 to 13, further comprising providing a third hydrocarbon feed stream comprising a third hydrocarbon to step (a), and the intermediate stream is produced by contacting the catalyst with the first hydrocarbon feed stream, the second hydrocarbon feed stream and the third hydrocarbon feed stream wherein the average molecular weight of the third hydrocarbon stream is higher than the average molecular weight of the second hydrocarbons stream. Aspect 15 is directed to the hydropyrolysis process of aspect 14, wherein the third hydrocarbon feed stream comprises crude oil, atmospheric residue, vacuum gas oils, unconverted oil from hydrocrackers, hydrowax, polyolefin oligomers, polymers dissolved or slurried in solvents, plastics, partially depolymerized plastics, plastic pyrolysis oil, hydrogenated plastic pyrolysis oil, heavy recycled crackable hydrocarbon stream, gas oils, vacuum gas oil and unconverted oil products from hydrocracking of plastics or any combinations thereof. Aspect 16 is directed to the hydropyrolysis process of aspects 14 or 15, wherein the third hydrocarbon feed stream is contacted with the catalyst downstream to contacting the catalyst with the second hydrocarbon feed stream. Aspect 17 is directed to the hydropyrolysis process of any one of aspects 1 to 16, wherein the step (a) and (b) is performed in a reactor and average hydrocarbon residence time in the reactor is 100 millisecond (ms) to 2 sec, preferably 100 ms to 1 sec. Aspect 18 is directed to the hydropyrolysis process of aspect 17, wherein the hydrogen source is provided to step (a) comprised in a lift stream and the lift stream can further comprise steam. Aspect 19 is directed to the hydropyrolysis process of any one of aspects 17 or 18, further comprising feeding an oxygenate at one or more positions of the reactor. Aspect 20 is directed to the hydropyrolysis process of aspect 19, wherein the process further comprises controlling local temperature of the reactor at the one or more positions where the oxygenate is fed: measuring the local temperature at the one or more positions where the oxygenate is fed; and increasing the oxygenate flow rate to the reactor if the local temperature at the one or more positions is lower than a desired temperature at the

one or more positions or decreasing the oxygenate flow rate to the reactor if the local temperature at the one or more positions is higher than a desired temperature at the one or more positions. Aspect 21 is directed to the hydropyrolysis process of any one of aspects 19 or 20, wherein the oxygenate is fed to the reactor comprised in one or more oxygenate stream, first hydrocarbon feed stream, second hydrocarbon feed stream, or third hydrocarbon feed stream, coke precursor stream or any combination thereof. Aspect 22 is directed to the hydropyrolysis process of any one of aspects 19 to 21, wherein the oxygenate is methanol. Aspect 23 is directed to the hydropyrolysis process of any one of aspects 19 to 22, wherein the reactor comprises one or more heaters and one or more sensors positioned on a reactor wall along a length of the reactor and the reactor temperature during the hydropyrolysis process is controlled with the one or more sensors, the one or more heaters and/or the oxygenate flow rate to the one or more positions of the reactor, such that a difference between a temperature at an inlet for the catalyst to the reactor and a temperature at an outlet for the spent catalyst from the reactor is less than 200°C, preferably less than 150 °C more preferably less than 100 °C. Aspect 24 is directed to a system for producing olefins and aromatics, the system comprising: a reactor comprising, a cylindrical body configured to comprise a first reaction zone and a second reaction zone, wherein the second reaction zone is in fluid communication with the first reaction zone and the first reaction zone and the second reaction zone are positioned along a length of the reactor; and one or more first heaters positioned on a wall along the length of the reactor, said reactor is configured to receive a first hydrocarbon feed stream, a cracking catalyst and a hydrogen source in the first reaction zone, contact the first hydrocarbon feed stream, the cracking catalyst and the hydrogen source to produce a used catalyst and an intermediate stream comprising olefins and aromatics, receive a coke precursor feed, the used catalyst and the intermediate stream in the second reaction zone, and contact the used catalyst, the intermediate stream and the coke precursor feed to produce a spent coked catalyst and a products stream comprising additional olefins and aromatics. Aspect 25 is directed to the system of aspect 24, wherein the reactor is configured to receive a second hydrocarbon feed stream in the first reaction zone downstream to the first hydrocarbon feed stream and the intermediate stream and used catalyst is produced by contacting the catalyst with the first hydrocarbon feed stream and the second hydrocarbon feed stream. Aspect 26 is directed to the system of aspect 25, wherein the reactor is configured to receive a third hydrocarbon feed stream in the first reaction zone downstream to the second hydrocarbon feed stream, and the intermediate stream and used catalyst is produced by contacting the catalyst with the first hydrocarbon feed stream, the second hydrocarbon feed stream and the third hydrocarbon feed stream. Aspect 27 is directed to the

system of any one of aspects 24 to 26, wherein the reactor further comprises an insulation layer positioned on an outer surface of a first heater layer formed by the one or more first heaters. Aspect 28 is directed to the system of aspect 27, wherein the reactor further comprises one or more second heaters positioned on an outer surface of the insulation layer. Aspect 29 is directed to the system of any one of aspects 24 to 28, wherein an average inner diameter of the reactor at the first reaction zone is higher than an average inner diameter of the reactor at the second reaction zone. Aspect 30 is directed to the system of any one of aspects 24 to 28, wherein an average inner diameter of the reactor at the first reaction zone is lower than an average inner diameter of the reactor at the second reaction zone. Aspect 31 is directed to the system of any one of aspects 24 to 30, wherein the reactor is a riser reactor or a downer reactor. Aspect 32 is directed to the system of any one of aspects 24 to 31, further comprising a 2nd reactor configured to process crackable hydrocarbons separated from the products stream after recovering light gas olefins, benzene, toluene, xylene, and ethyl benzene from the products stream. Aspect 33 is directed to the system of aspect 32, wherein residence time in the reactor and the second reactor is configured to be independently 100 ms to 1 sec. Aspect 34 is directed to the system of any one of aspects 24 to 33, wherein the reactor further comprises a plurality of nozzles arranged along the length of the reactor, configured to introduce one or more oxygenates to the reactor. Aspect 35 is directed to the system of any one of aspects 24 to 34, wherein the number of nozzles in the first reaction zone is higher than the number of nozzles in the second reaction zone. Aspect 36 is directed to the system of any one of aspects 24 to 35, further comprising a regeneration unit configured to receive the spent coked catalyst from the reactor and a regeneration stream comprising oxygen (O₂), contact the spent coked catalyst and oxygen to regenerate the cracking catalyst.

EXAMPLES

[0059] The present invention will be described in greater detail by way of specific examples. The following examples are offered for illustrative purposes only and are not intended to limit the invention in any manner. Those of skill in the art will readily recognize a variety of non-critical parameters that can be changed or modified to yield essentially the same results.

Example 1

Hydropyrolysis of West Texas Blend crude oil boiling cut (370 °C to 415 °C)

[0060] Hydropyrolysis was carried out on a West Texas blend crude oil cut (370 °C to 415 °C) in a lab reactor with a fluidizing stream containing 10 vol.% of H₂ and 90 vol.% of N₂. The

reactor is an in-situ fluidized bed tubular reactor having a length of 783 mm and an inner diameter of 15 mm, and was housed in a split-zone 3-zone tubular furnace with independent temperature control for each zone. The size of each heated zone was 9.3 inches (236.2 mm). The overall heated length of the reactor placed inside the furnace was 591 mm. The reactor wall temperature was measured at the center of each zone and was used to control the heating of each furnace zone. The reactor had a conical bottom and the reactor bed temperature was measured using a thermocouple housed inside a thermowell and placed inside the reactor at the top of the conical bottom. Also, the reactor wall temperature was measured at the conical bottom to ensure that the bottom of the reactor was hot. The reactor bottom was placed at the middle of the furnace bottom zone for minimizing the effect of furnace end cap heat losses and maintaining the reactor bottom wall temperature within a difference of 20° C of the internal bed temperature measured. The catalyst used is a combination of FCC catalyst and ZSM-5 additive in the ratio (67.5 wt. % and 37.5 %wt. % respectively). The conditions and the product distribution is listed in Table 1, Run # 3, 4 and 5.

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Example 2:**Pyrolysis of West Texas Blend crude oil boiling cut (370-415 °C)- Comparative example.**

[0061] Example 2 was performed with conditions similar to Example 1 except that the fluidizing stream was 100% N₂ i.e. no H₂ in the fluidizing stream. The conditions and product distribution is listed in Table 1 (Run # 1 and 2).

[0062] Results from Example 1 (Table 1, run # 3, 4 and 5) and Example 2 (Table 1, run # 1 and 2) show that, presence of hydrogen in the reaction environment has a significant effect on the product distribution and coke formation. The light gas olefins has increased by at least 3 wt. % and coke reduced by at least 1 wt. %. This has enhanced the light gas olefins per unit coke from 9 to 10 to 14 to 17 wt./wt. although the average cup mixing temperature is lower in Example 1 in two of the three cases as compared to Example 2. In addition there is reduction of heavies formation. Results indicate that the presence of hydrogen in the reaction environment, as in Example 1, keeps the catalyst relatively more active as less coke gets deposited on the surface of the catalyst. This in turn results in higher light gas olefins and lesser heavies formation.

Table 1: Conditions and the product distribution for High severity pyrolysis (Example 2) and hydropyrolysis (Example 1).

	Units	High Severity pyrolysis		Hydropyrolysis		
Run#		1	2	3	4	5
Feed		West Texas Blend Crude oil 370-415 °C boiling cut				
Fluidizing gas composition	mol. %	100% N ₂		90% N ₂ : 10% H ₂		
C/F	wt./ wt.	6.2	5.8	6.0	6.1	5.9
1 min average cup mix temperature	°C	688	687	685.6	684.8	688
Yields						
Ethylene	wt. %	12.1	11.8	12.4	12.7	14.9
Propylene	wt. %	12.1	13.0	14.0	14.6	12.8
Butenes	wt. %	8.7	9.2	9.8	9.6	9.1
	wt. %					
Light gas olefins	wt. %	33.0	34.0	36.1	36.9	36.7
Coke	wt. %	3.7	3.3	2.5	2.2	2.2
Light gas olefins / unit coke	wt./ wt.	9.0	10.2	14.6	17.1	16.4
Gasoline (IBP-220 °C)	wt. %	38.5	32.7	34.6	38.8	32.3
Diesel (220-370 °C)	wt. %	5.2	8.5	5.7	4.4	3.9
Heavies (370+ °C)	wt. %	2.8	5.4	2.8	1.2	1.5

Example 3

- 5 **Hydropyrolysis of West Texas Blend crude oil boiling cut (370 °C to 415 °C) mixed with varying amount of methanol**

[0063] Example 3 was performed with conditions similar to Example 1 except that the feed was a mixture of West Texas Blend crude oil boiling cut (370-415 °C) (WTB cut, 370-415 °C) and methanol with weight % ratios 95/5 (Table 2, run 6), 90/10 (Table 2, run 7) and 85/15 (Table 2, run 8) respectively. The conditions and product distributions are listed in Table 2 as runs 6 to 8. Although the furnace set temperature in these cases was the same as in run 1 to 5 of Table 1, the average cup mixing temperature in Table 2 for runs 6 to 8 was higher when methanol was used with the main feed. This is an evidence to show that cracking of methanol is exothermic and generates local heat that results in increase in temperature. This local exothermicity can be advantageously used in a commercial reactor for maintaining higher local temperatures as desired or for imposing a temperature profile by controlling methanol addition rate along the length of the reactor. Run 9 in the Table 2 corresponds to pure methanol cracking and it can be clearly seen that for the same furnace set temperature, a higher cup mix temperature results. Cup mix temperature is the 1st min average temperature after feed introduction in the lab reactor. In commercial reactor, it is the average temperature in the immediate vicinity (within 1 m) of the corresponding feed introduction location. The light gas olefins has decreased on blending methanol. This is due to the dilution effect of co-feeding methanol in the feed. Since methanol also cracks, the gasoline yield has increased. Also co-feeding of methanol reduces both coke and heavies formation. This can well be attributed to the better atomization of the feed due to the lighter oxygenate and resulting in better contact of feed and catalyst. As a result of the lower coke on the catalyst by this synergy effect, the catalyst in the hydrolysis can be kept active even by this effect in addition to being kept active by hydrogen in the fluidizing gas.

Table 2: Conditions and the product distribution for and hydropyrolysis in presence of methanol (Example 3).

Run#		5	6	7	8	9
Feed		WTB cut, 370-415 °C	95 wt. % WTB cut, 370-415 °C + 5 wt. % methanol	90 wt. % WTB cut, 370-415 °C + 10 wt. % methanol	85 wt. % WTB cut, 370-415 °C + 15 wt. % methanol	100 wt. % methanol
Fluidizing gas composition	mol. %	90% N ₂ : 10% H ₂				
C/F	wt./ wt.	5.9	6.0	6.1	5.9	6.0
1 min average cup mix temperature	°C	688	687	690.2	690.2	702.4
Yields						
Ethylene	wt. %	14.9	12.5	12.7	13.1	5.9
Propylene	wt. %	12.8	13.0	12.4	12.2	4.8
Butenes	wt. %	9.1	9.3	8.2	8.4	1.4
	wt. %					
Light gas olefins	wt. %	36.7	34.9	33.4	33.7	12
Coke	wt. %	2.2	1.4	1.8	1.2	0.8
Light gas olefins / unit coke	wt./ wt.	16.4	25.3	18.3	28.3	14.4
Gasoline (IBP-220 °C)	wt. %	32.3	36.4	34.7	36.5	
Diesel (220-370 °C)	wt. %	3.9	7.1	8.2	7.4	
Heavies (370+ °C)	wt. %	1.5	1.6	1.7	1.7	

Example 4

5 **Hydropyrolysis and high severity pyrolysis (comparative) of plastics feed.**

- [0064] Hydropyrolysis and high severity pyrolysis of plastic feed was performed. For a constant coke yield of 5 wt. %, this translates to a comparison of benefits in Table 3 below. Based on the predictions and from lab data, it can be inferred that hydropyrolysis can result in up to 5 wt. % increase in yields of light olefins, benzene, toluene, xylene and ethylbenzene.
- 5 FIG. 8 demonstrates the advantages of hydropyrolysis over high severity pyrolysis for plastic feed

Table 3: Prediction of yield benefits from hydropyrolysis at constant coke yield based on lab yields of high value chemicals per unit coke

	Experiment 1	Comparative experiment
Regenerator coke burn capacity, wt. % of feed	5	5
Light olefins/coke (w/w)	6.4	5.8
C ₆ -C ₈ aromatics/coke (w/w)	5.1	4.2
Light olefins yield, wt. %	32	29
C ₆ -C ₈ aromatics yield, wt. %	25.5	20.5

CLAIMS

1. A hydropyrolysis process to produce higher yields of olefins and aromatics, the process comprising:
 - (a) contacting a first hydrocarbon feed stream comprising a first hydrocarbon with a cracking catalyst and a hydrogen source under conditions sufficient to produce a used catalyst and an intermediate stream comprising olefins and aromatics; and
 - (b) contacting the used catalyst and the intermediate stream with a coke precursor stream to produce a spent coked catalyst and a products stream comprising additional olefins and aromatics.
2. The hydropyrolysis process of claim 1, wherein a catalyst to feed (C/F) ratio in step (a) is greater than the C/F ratio in step (b).
3. The hydropyrolysis process of any of claims 1 or 2, wherein the wt. % of coke in the used catalyst is lower than the wt. % of coke in the spent coked catalyst.
4. The hydropyrolysis process of any of claims 1 or 2, wherein the process further comprises regenerating the spent coked catalyst.
5. The hydropyrolysis process of claim 4, wherein the regenerated catalyst is recycled to step (a).
6. The hydropyrolysis process of any of claim 1 or 2, wherein the hydrogen source is hydrogen (H₂) gas, methane, ethane, ethylene, propane, propylene, butanes, butenes or any combinations thereof.
7. The hydropyrolysis process of any of claims 1 or 2, wherein the contacting condition in step (a) comprises a temperature of 500 °C to 750 °C.
8. The hydropyrolysis process of any of claims 1 or 2, wherein the contacting condition in step (a) comprises a temperature of 700 °C to 850 °C.
9. The hydropyrolysis process of any of claims 1 or 2, wherein the first hydrocarbon feed stream comprises naphtha, condensates, gas oils, C₃ and C₄ saturated gas, cracked naphtha stream, recycled crackable hydrocarbon stream comprising C₃ and C₄ saturated gas or any combinations thereof.

10. The hydropyrolysis process of any of claims 1 or 2, wherein the coke precursor stream comprises cycle oils, coker streams, crude oil, slurry oil, carbon black oil, cracked distillates, cracked oils, vacuum residue or any combination thereof.
11. The hydropyrolysis process of any of claims 1 or 2, further comprising providing a second hydrocarbon feed stream comprising a second hydrocarbon to step (a), and the intermediate stream is produced by contacting the catalyst with the first hydrocarbon feed stream and the second hydrocarbon feed stream, wherein the average molecular weight of the second hydrocarbon feed stream is higher than the average molecular weight of the first hydrocarbon feed stream.
12. The hydropyrolysis process of claim 11, wherein the second hydrocarbon feed stream comprises crude oil, atmospheric residue, vacuum gas oils, unconverted oil from hydrocrackers, hydrowax, polyolefin oligomers, plastics or polymers dissolved or slurried in solvents, plastics, partially depolymerized plastics, plastic pyrolysis oil, hydrogenated plastic pyrolysis oil, recycled naphtha and gas oil streams, naphtha, gas oils, vacuum gas oil and unconverted oil products from hydrocracking of plastics or any combinations thereof.
13. The hydropyrolysis process of claims 11 or 12, wherein the second hydrocarbon feed stream is contacted with the catalyst downstream to contacting the catalyst with the first hydrocarbon feed stream.
14. The hydropyrolysis process of any of claims 11 or 12, further comprising providing a third hydrocarbon feed stream comprising a third hydrocarbon to step (a), and the intermediate stream is produced by contacting the catalyst with the first hydrocarbon feed stream, the second hydrocarbon feed stream and the third hydrocarbon feed stream wherein the average molecular weight of the third hydrocarbon stream is higher than the average molecular weight of the second hydrocarbons stream.
15. The hydropyrolysis process of claim 14, wherein the third hydrocarbon feed stream comprises crude oil, atmospheric residue, vacuum gas oils, unconverted oil from hydrocrackers, hydrowax, polyolefin oligomers, polymers dissolved or slurried in solvents, plastics, partially depolymerized plastics, plastic pyrolysis oil, hydrogenated plastic pyrolysis oil, heavy recycled crackable hydrocarbon stream, gas oils, vacuum gas oil and unconverted oil products from hydrocracking of plastics or any combinations thereof.

16. The hydropyrolysis process of claim 14, wherein the third hydrocarbon feed stream is contacted with the catalyst downstream to contacting the catalyst with the second hydrocarbon feed stream.
17. The hydropyrolysis process of any of claims 1 to 2, wherein the step (a) and (b) is performed in a reactor and average hydrocarbon residence time in the reactor is 100 ms to 2 sec, preferably 100 ms to 1 sec.
18. The hydropyrolysis process of claim 17, wherein the hydrogen source is provided to step (a) comprised in a lift stream and the lift stream can further comprise steam.
19. The hydropyrolysis process of any of claims 17 or 18, further comprising feeding an oxygenate at one or more positions of the reactor.
20. The hydropyrolysis process of claim 19, wherein the process further comprises controlling local temperature of the reactor at the one or more positions where the oxygenate is fed:
 - measuring the local temperature at the one or more positions where the oxygenate is fed; and
 - increasing the oxygenate flow rate to the reactor if the local temperature at the one or more positions is lower than a desired temperature at the one or more positions or decreasing the oxygenate flow rate to the reactor if the local temperature at the one or more positions is higher than a desired temperature at the one or more positions.