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OF WASTE PLASTICS TO FINAL
PETROCHEMICAL PRODUCTS**(30) **Foreign Application Priority Data**

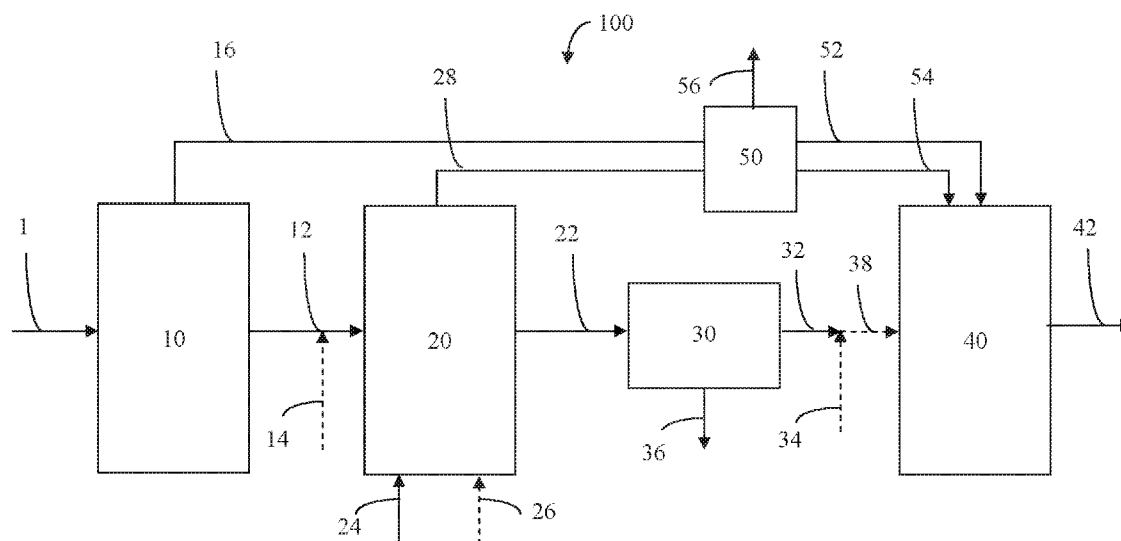
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(57)

ABSTRACT

An integrated process for the conversion of waste plastics to high value products. The integrated process allows for operation with a hydroprocessing reactor which provides simultaneous hydrogenation, dechlorination, and hydrocracking of components of a hydrocarbon stream to specifications which meet steam cracker requirements.



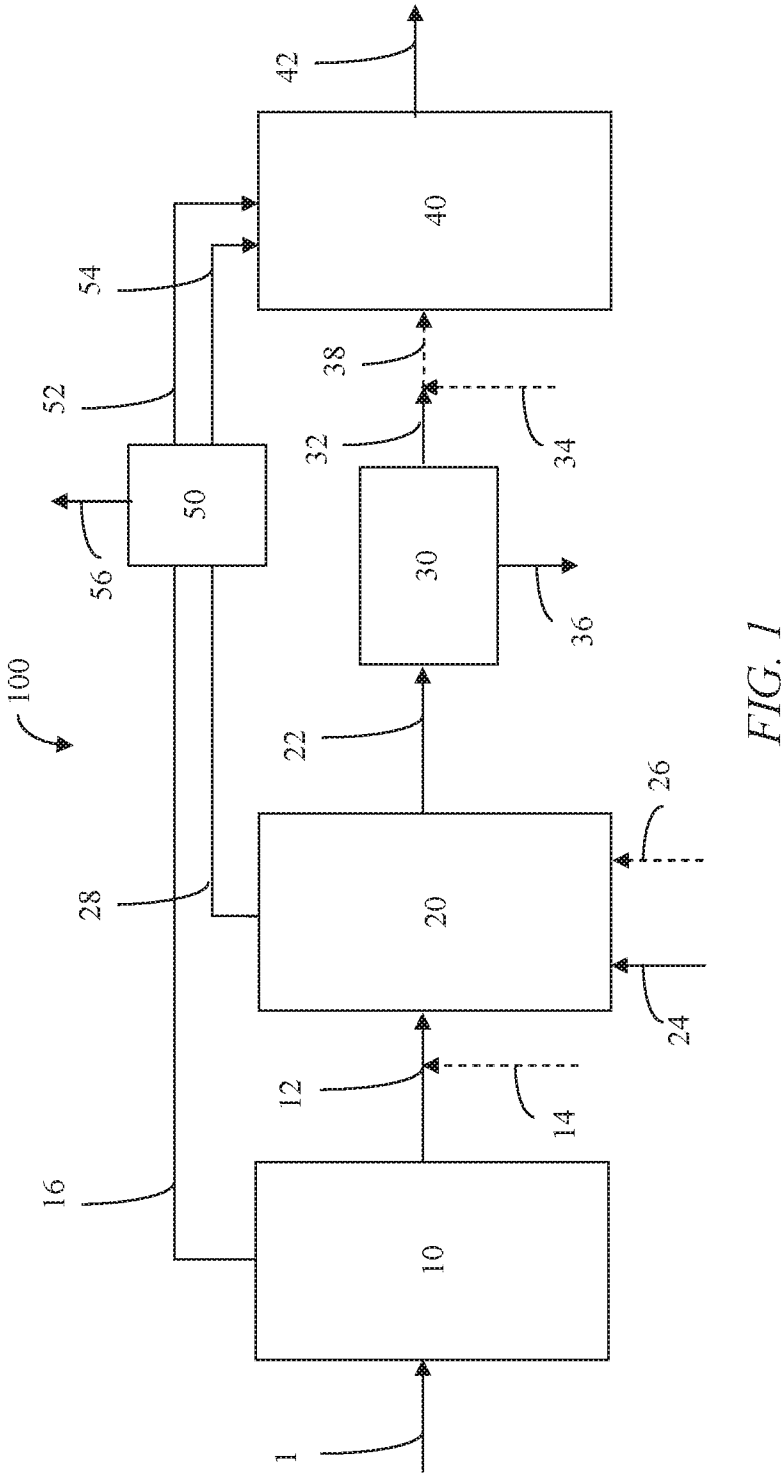


FIG. 1

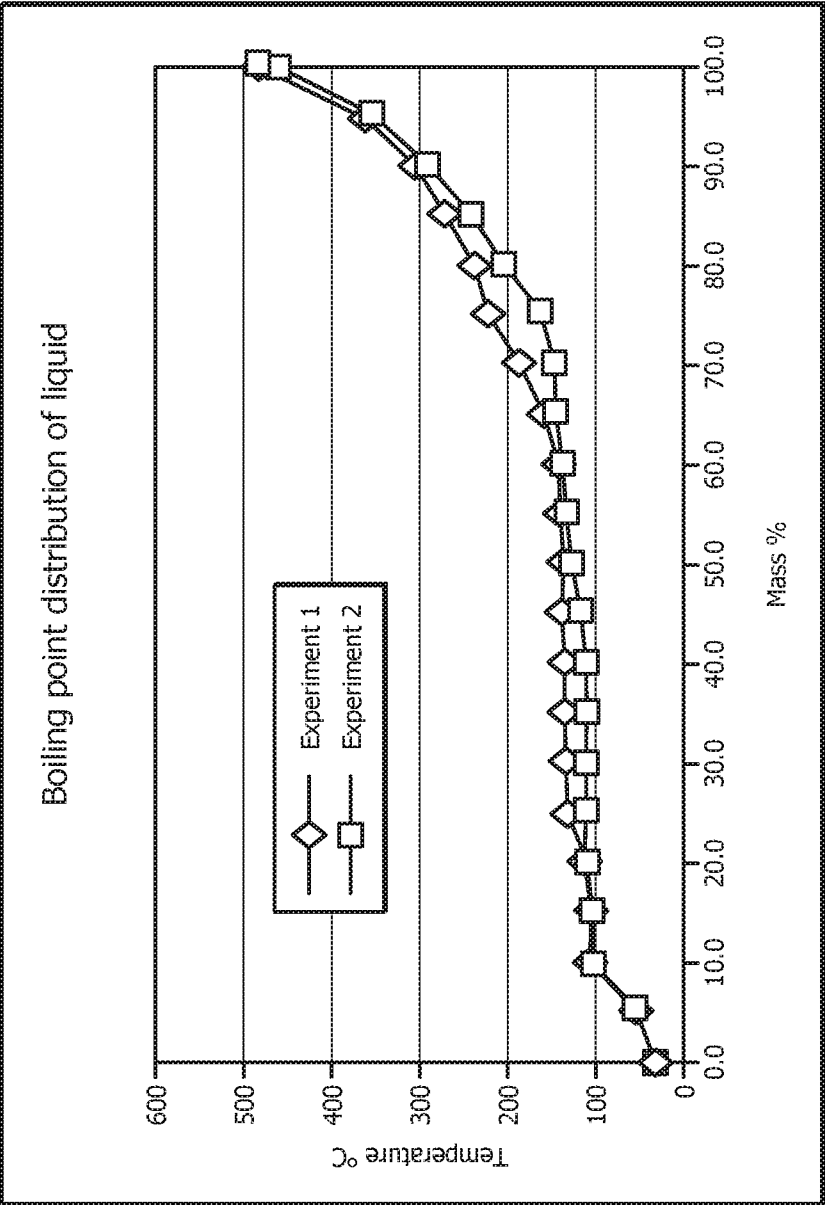
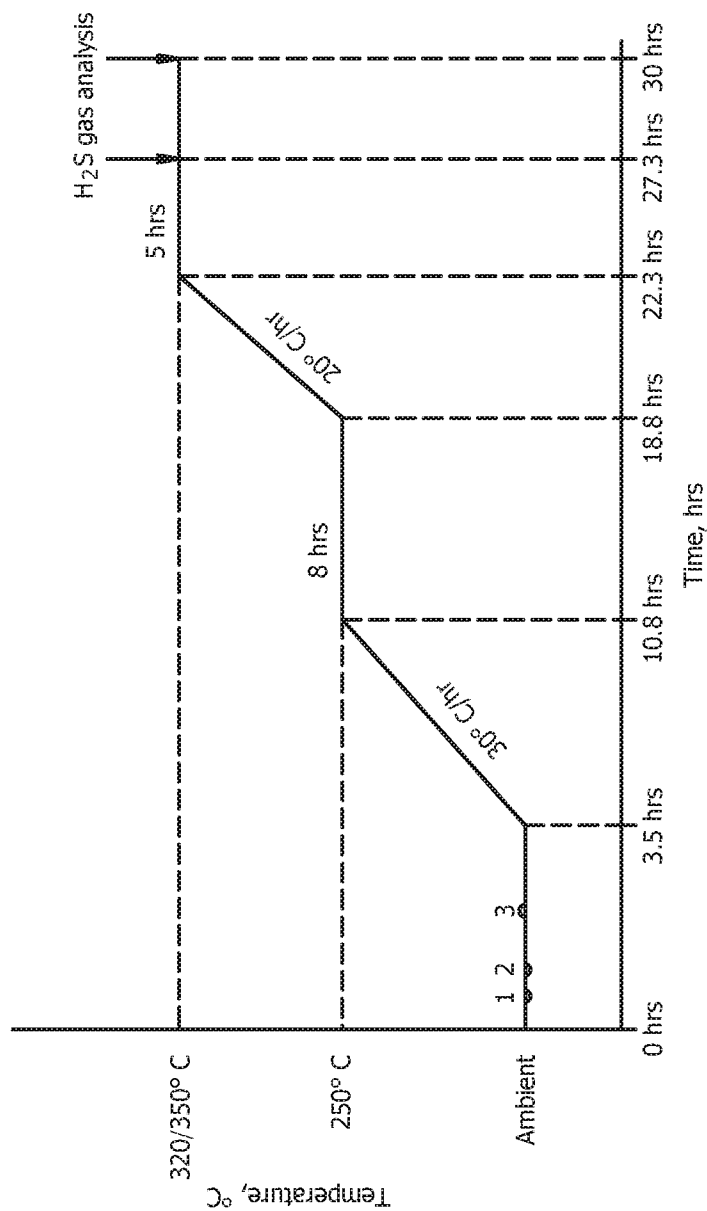


FIG. 2



1. H₂ purge for 30-60 mins at 40-60 barg at ambient temperature
2. Stop H₂
3. Pump sulfiding feed for 3hrs at 3hr⁻¹ WHSV without H₂ purge at 40-60 barg at ambient temperature

FIG. 3

INTEGRATED PROCESS FOR CONVERSION OF WASTE PLASTICS TO FINAL PETROCHEMICAL PRODUCTS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application is a continuation of and claims priority to International Application No. PCT/IB2016/051136 filed Mar. 1, 2016, entitled "An Integrated Process for Conversion of Waste Plastics to Final Petrochemical Products," which claims priority to U.S. Provisional Application No. 62/201,669 filed on Aug. 6, 2015, entitled "An Integrated Process for Conversion of Waste Plastics to Final Petrochemical Products," and Indian Provisional Application No. 1170/CHE/2015 filed Mar. 10, 2015 entitled "An Integrated Process for Conversion of Waste Plastics to Final Petrochemical Products," which applications are incorporated by reference herein in their entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to the treatment of hydrocarbon streams resulting from pyrolysis of waste plastics for use in downstream processes.

BACKGROUND

[0003] Waste plastics contain polyvinylchloride (PVC). Through a pyrolysis process, waste plastics can be converted to gas and liquid products. These liquid products contain paraffins, i-paraffins (iso-paraffins), olefins, naphthenes, and aromatic components along with organic chlorides in concentrations of hundreds of ppm. However, the liquid products of a pyrolysis process (pyrolysis oils) are off-spec for use as a feedstock for steam crackers because steam cracker feed specifications require chloride levels less than 3 ppm, olefin content less than 1 wt %, and boiling end point requirements of 370° C.

SUMMARY

[0004] Disclosed herein is a process for converting waste plastics to a high value product comprising converting the waste plastics to a hydrocarbon stream in a liquid phase, contacting the hydrocarbon stream with a hydroprocessing catalyst in the presence of hydrogen to yield a hydrocarbon product comprising C₁ to C₄ gases and C₅+ liquid hydrocarbons, recovering the C₅+ liquid hydrocarbons in a treated hydrocarbon stream from the hydrocarbon product, and feeding the treated hydrocarbon stream or a blended hydrocarbon stream comprising the treated hydrocarbon stream to a steam cracker to yield the high value product, wherein the treated hydrocarbon stream or blended hydrocarbon stream meets steam cracker feed requirements for chloride content, olefin content, and boiling end point.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 illustrates a hydroprocessing system for converting plastic waste to a high value product by simultaneously dechlorinating chloride compounds, hydrogenating olefins, and hydrocracking heavy hydrocarbon molecules contained in a hydrocarbon stream which contains a pyrolysis oil to levels suitable for introduction to a steam cracker.

[0006] FIG. 2 is a graph of the boiling point distribution for a liquid product of a low severity pyrolysis process, showing temperature versus mass percent.

[0007] FIG. 3 is a graph of a staged catalyst sulphiding protocol, showing temperature versus time.

DETAILED DESCRIPTION

[0008] Other than in the operating examples or where otherwise indicated, all numbers or expressions referring to quantities of ingredients, reaction conditions, and the like, used in the specification and claims are to be understood as modified in all instances by the term "about." Various numerical ranges are disclosed herein. Because these ranges are continuous, they include every value between the minimum and maximum values. The endpoints of all ranges reciting the same characteristic or component are independently combinable and inclusive of the recited endpoint. Unless expressly indicated otherwise, the various numerical ranges specified in this application are approximations. The endpoints of all ranges directed to the same component or property are inclusive of the endpoint and independently combinable. The term "X or more" means that the named component is present in an amount of the value X, and values which are more than X.

[0009] The terms "a," "an," and "the" do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item. As used herein the singular forms "a," "an," and "the" include plural referents.

[0010] As used herein, "combinations thereof" is inclusive of one or more of the recited elements, optionally together with a like element not recited, e.g., inclusive of a combination of one or more of the named components, optionally with one or more other components not specifically named that have essentially the same function. As used herein, the term "combination" is inclusive of blends, mixtures, alloys, reaction products, and the like.

[0011] Reference throughout the specification to "an embodiment," "embodiments," "another embodiment," "other embodiments," "alternative embodiments," "additional embodiments," "some embodiments," and so forth (e.g., the use of "additionally" and/or "alternatively" in the context of describing one or more embodiments), means that a particular element (e.g., feature, structure, property, and/or characteristic) described in connection with the embodiment is included in at least an embodiment described herein, and may or may not be present in other embodiments. In addition, it is to be understood that the described element(s) can be combined in any suitable manner in the various embodiments.

[0012] Disclosed herein are embodiments of a process for converting waste plastics to a high value product. Embodiments of the process include converting the waste plastics to a hydrocarbon stream in a liquid phase, converting the waste plastics to a pyrolysis light gas stream containing C₁ to C₄ hydrocarbons, contacting the hydrocarbon stream with a hydroprocessing catalyst in the presence of hydrogen (H₂) to yield a hydrocarbon product, recovering a treated hydrocarbon stream comprising C₅+ hydrocarbons from the hydrocarbon product, recovering a hydroprocessed light gas stream from the hydrocarbon product, feeding the treated hydrocarbon stream or a blended hydrocarbon stream comprising the treated hydrocarbon stream to a steam cracker to yield the high value product, feeding the pyrolysis light gas stream to the steam cracker, feeding the hydroprocessed light gas stream to the steam cracker, or combinations thereof. The

treated hydrocarbon stream or blended hydrocarbon stream meets steam cracker feed requirements. The pyrolysis light gas stream may be fed to the steam cracker directly, or after treating the pyrolysis light gas stream in a scrubbing unit to yield a treated pyrolysis light gas stream which is subsequently fed to the steam cracker. The hydroprocessed light gas stream may be fed to the steam cracker directly, or after treating the hydroprocessed light gas stream in a scrubbing unit to yield a treated hydroprocessed light gas stream which is subsequently fed to the steam cracker. Converting the waste plastics to a hydrocarbon stream in a liquid phase and converting the waste plastics to a pyrolysis light gas stream containing C₁ to C₄ hydrocarbons may occur simultaneously via pyrolysis of the waste plastics.

[0013] Embodiments of the process are described in more detail with reference to FIG. 1. FIG. 1 illustrates a hydroprocessing for converting plastic waste to a high value product by simultaneously dechlorinating chloride compounds, hydrogenating olefins, and hydrocracking heavy hydrocarbon molecules contained in a hydrocarbon stream 12 which contains a pyrolysis oil (e.g., plastic pyrolysis oil, tire pyrolysis oil) to levels suitable for introduction to a steam cracker 30. The system 100 includes a pyrolysis unit 10, a hydroprocessing reactor 20, a separator 30, and a steam cracker 40. Waste plastic is either placed in the pyrolysis unit 10 or fed to the pyrolysis unit 10 via waste plastic stream 1. In the pyrolysis unit 10, the plastic waste stream is converted via pyrolysis reactions to pyrolysis gases and a liquid pyrolysis oil. The pyrolysis gases flow from the pyrolysis unit 10 via a pyrolysis light gas stream 16 directly to the steam cracker 40 or to a scrubbing unit 50. The liquid pyrolysis oil flows from the pyrolysis unit 10 via hydrocarbon stream 12. The hydrocarbon stream 12 feeds to the hydroprocessing reactor 20, and the reaction product effluent of the hydroprocessing reactor 20 flows from the hydroprocessing reactor 20 in the hydrocarbon product stream 22 to the separator 30. In separator 30, a treated product (e.g., in gas or liquid form) is recovered from the hydrocarbon product stream 22 and flows from the separator 30 via treated hydrocarbon stream 32, with one or more of sulphur-containing gases and chlorine-containing gases flowing from the separator 30 in hydroprocessed light gas stream 36. C₁ to C₄ hydrocarbon gases which are generated in the hydroprocessing reactor 20 may flow directly to a separator 30, where the C₁ to C₄ hydrocarbon gases are recovered in a hydroprocessed light gas stream 36 for flow directly to the steam cracker 40, to a scrubbing unit 50, or a combination of direct flow to the steam cracker 40 and flow to the scrubbing unit 50 (e.g., a portion of the pyrolysis light gas stream bypasses the scrubbing unit).

[0014] Embodiments of the disclosure contemplate a second hydroprocessing reactor and a second separator may be placed in between separator 30 and treated hydrocarbon stream 32. The treated product flowing from the separator 30 in treated hydrocarbon stream 32, in such embodiments, may contain residual sulphur, and the second hydroprocessing reactor/second separator combination may treat the treated product flowing from the separator 30 to completely remove the sulphur such that a second treated product flowing in the treated hydrocarbon stream 32 from the second separator contains less than 200, 100, 90, 80, 70, 60, 50, 40, 30, 20, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, 0.5, 0.1 ppmw S based on total weight of the treated hydrocarbon stream 32. In embodiments having a second hydroprocessing reactor, C₁ to C₄ hydrocarbon gases generated in the second hydroprocessing reactor may

flow from the second hydroprocessing reactor in a second hydroprocessed light gas stream. Similar to the hydroprocessed light gas stream 36 flowing from the separator 30, the second hydroprocessed light gas stream may flow from a second separator directly to the steam cracker 40, to the scrubbing unit 50, or a combination of direct flow to the steam cracker 40 and flow to the scrubbing unit 50 (e.g., a portion of the pyrolysis light gas stream bypasses the scrubbing unit).

[0015] The treated product in the treated hydrocarbon stream 32 may flow directly (e.g., without any separations or fractionations of the treated hydrocarbon stream 32) or via blended hydrocarbon stream 38 (e.g., without any separations or fractionations of the treated hydrocarbon stream 32 and blended hydrocarbon stream 38) to a steam cracker 40, from which high value products flow in stream 42.

[0016] Waste plastics which are loaded into or fed to the pyrolysis unit 10 via waste plastic stream 1 may include post-consumer waste plastics. Examples of waste plastics which can be used include chlorinated plastics (e.g., chlorinated polyethylene), polyvinylchloride, non-chlorinated plastics (e.g., polyethylene, polystyrene, polypropylene, copolymers, etc.), or mixtures thereof. Waste plastics as disclosed herein also include used tires.

[0017] Waste plastics in the pyrolysis unit 10 are subjected to a pyrolysis process to convert the waste plastics to one or more pyrolysis oils which flow from the pyrolysis unit 10 via hydrocarbon stream 12. The pyrolysis processes in the pyrolysis unit 10 may be low severity or high severity. Low severity pyrolysis processes may occur at a temperature of 300° C. to 450° C., may produce pyrolysis oils rich in mono- and diolefins as well as a significant amount of aromatics, and may include chloride compounds in amounts which cause the hydrocarbon stream 12 to have the chloride compound concentrations disclosed herein. High severity pyrolysis processes may occur at a temperature of 450° C. to 750° C. and may produce pyrolysis oils rich in aromatics. The liquid product of the high severity processes may include chloride compounds which cause the hydrocarbon stream 12 to have the chloride compound concentrations disclosed herein.

[0018] In embodiments, the pyrolysis unit 10 may be one or more vessels configured to convert waste plastics into gas phase and liquid phase products (e.g., simultaneously). The one or more vessels may contain one or more beds of inert material or pyrolysis catalyst comprising sand, zeolite, or combinations thereof. Generally, the pyrolysis catalyst is capable of transferring heat to the components subject to the pyrolysis process in the pyrolysis unit 10. In an embodiment where the pyrolysis unit 10 is two vessels, the pyrolysis process may be divided into a first stage which is performed in the first vessel and in a second stage fluidly connected downstream of the first stage which is performed in the second vessel. The first stage may utilize thermal cracking of the waste plastics, and the second stage may utilize catalytic cracking of the waste plastics to yield the hydrocarbon stream 12 flowing from the second stage. Alternatively, the first stage may utilize catalytic cracking of the waste plastics, and the second stage may utilize thermal cracking of the waste plastics to yield the hydrocarbon stream 12 flowing from the second stage.

[0019] In additional or other embodiments, the pyrolysis unit 10 may include one or more equipment configured to convert waste plastics into gas phase and liquid phase products. The one or more equipment may or may not contain any inert material or pyrolysis catalyst as described above.

Examples of such equipment include one or more of heated extruders, heated rotating kiln, heated tank-type reactors, empty heated vessels, enclosed heated surfaces where plastic flows down along the wall and cracks, vessels surrounded by ovens or furnaces or other equipment offering a heated surface to assist in cracking.

[0020] In one or more embodiments of the pyrolysis unit **10**, a head space purge gas is utilized in all or a portion of the pyrolysis stage(s) (conversion of waste plastics to a liquid phase and/or gas phase products) to enhance cracking of plastics, produce valuable products, provide a feed for steam cracking, or combinations thereof. The head space purge gas may include can utilize hydrogen (H_2), nitrogen (N_2), steam, product gases, or combinations thereof. The use of a head space purge gas assists in the dechlorination in the pyrolysis unit **10**. The use of hydrogen in the pyrolysis unit **10** has beneficial effects of i) reducing the coke lay down as a result of cracking, ii) keeps catalyst used (if any) in the process in an active condition, iii) improves removal of chloride from stream **1** such that the hydrocarbon stream **12** from pyrolysis unit **10** is substantially dechlorinated with respect to waste plastic stream **1** which minimizes the chloride removal requirement in hydroprocessing reactor **20**, iv) reduces diolefins in hydrocarbon stream **12**, v) helps operate the pyrolysis unit **10** at reduced temperatures for same levels of conversion of waste plastic stream **1** in the pyrolysis unit **10**, or combinations of i)-v).

[0021] An example of a pyrolysis process for waste plastics is disclosed in U.S. Pat. No. 8,895,790, which is incorporated by reference in its entirety. Another example of a pyrolysis process is disclosed in U.S. Provisional Patent Application No. 62/025,762, titled "Upgrading Hydrogen Deficient Streams Using Hydrogen Donor Streams in a Hydrolysis Process," filed Jul. 17, 2014, which is incorporated by reference in its entirety.

[0022] The hydrocarbon stream **12** generally includes one or more pyrolysis oils (e.g., plastic pyrolysis oil, tire pyrolysis oil). In embodiments, the hydrocarbon stream **12** may include one or more pyrolysis oils as described above which is blended with a heavier oil (e.g., a naphtha or diesel, via spiking stream **14**). In such embodiments, blending the treated hydrocarbon stream **32** with a non-chlorinated stream **34** as described for embodiments below may additionally occur; alternatively, the subsequent blending may not occur.

[0023] In an embodiment wherein the hydrocarbon stream **12** does not contain the one or more sulphides in the concentrations disclosed herein, the hydrocarbon stream **12** may be spiked with the one or more sulphides, via a spiking stream **14** (discussed in more detail below).

[0024] Examples of the components which may be included in the hydrocarbon stream **12** include paraffins (n-paraffin, i-paraffin, or both), olefins, naphthenes, aromatic hydrocarbons, or combinations thereof. When the one or more hydrocarbons includes all the listed hydrocarbons, the group of hydrocarbons may be collectively referred to as a PONA feed (paraffin, olefin, naphthene, aromatics) or PIONA feed (n-paraffin, paraffin, olefin, naphthene, aromatics).

[0025] Any paraffin may be included in the hydrocarbon stream **12**. Examples of paraffins which may be included in the hydrocarbon stream **12** include, but are not limited to, C_1 to C_{22} n-paraffins and i-paraffins. In an embodiment, the concentration of paraffins in the hydrocarbon stream **12** may be less than 10 wt % based on the total weight of the hydro-

carbon stream **12**. Alternatively, the concentration of paraffins in the hydrocarbon stream **12** may be 10 wt %, 20 wt %, 30 wt %, 40 wt %, 50 wt %, 60 wt %, or more based on the total weight of the hydrocarbon stream **12**. While embodiments include paraffins of carbon numbers up to 22, the disclosure is not limited to carbon number 22 as an upper end-point of the suitable range of paraffins, and the paraffins can include higher carbon numbers, e.g., 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, and higher. In embodiments, at least a portion of the paraffins in the hydrocarbon stream **12** comprises at least a portion of the heavy hydrocarbon molecules.

[0026] Any olefin may be included in the hydrocarbon stream **12**. Examples of olefins which may be included in hydrocarbon stream **12** include, but are not limited to, C_2 to C_{10} olefins and combinations thereof. In an embodiment, the concentration of olefins in the hydrocarbon stream **12** may be less than 10 wt % based on the total weight of the hydrocarbon stream **12**. Alternatively, the concentration of olefins in the hydrocarbon stream **12** may be 10 wt %, 20 wt %, 30 wt %, 40 wt % or more based on the total weight of the hydrocarbon stream **12**. In embodiments, at least a portion of the one or more olefins in the hydrocarbon stream **12** comprise at least a portion of the heavy hydrocarbon molecules. Alternatively, none of the heavy hydrocarbon molecules in the hydrocarbon stream **12** are olefins. While embodiments include olefins of carbon numbers up to 10, the disclosure is not limited to carbon number 10 as an upper end-point of the suitable range of olefins, and the olefins can include higher carbon numbers, e.g., 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, and higher.

[0027] In an embodiment, the hydrocarbon stream **12** comprises no olefins.

[0028] Any naphthene may be included in the hydrocarbon stream **12**. Examples of naphthenes include, but are not limited to, cyclopentane, cyclohexane, cycloheptane, and cyclooctane. In an embodiment, the concentration of naphthenes in the hydrocarbon stream **12** may be less than 10 wt % based on the total weight of the hydrocarbon stream **12**. Alternatively, the concentration of naphthenes in the hydrocarbon stream **12** may be 10 wt %, 20 wt %, 30 wt %, 40 wt % or more based on the total weight of the hydrocarbon stream **12**. While embodiments include naphthenes of carbon numbers up to 8, the disclosure is not limited to carbon number 8 as an upper end-point of the suitable range of naphthenes, and the naphthenes can include higher carbon numbers, e.g., 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, and higher. In embodiments, at least a portion of the naphthenes in the hydrocarbon stream **12** comprise at least a portion of the heavy hydrocarbon molecules.

[0029] Any aromatic hydrocarbon may be included in the hydrocarbon stream **12**. Aromatic hydrocarbons suitable for use in the hydrocarbon stream **12** include, but are not limited to, benzene, toluene, xylenes, ethyl benzene, or combinations thereof. In an embodiment, the concentration of aromatic hydrocarbons in the hydrocarbon stream **12** may be less than 10 wt % based on the total weight of the hydrocarbon stream **12**. Alternatively, the concentration of aromatic hydrocarbons in the hydrocarbon stream **12** may be 10 wt %, 20 wt %, 30 wt %, 40 wt % or more based on the total weight of the hydrocarbon stream **12**. While embodiments include aromatic hydrocarbons of carbon numbers up to 8, the disclosure is not limited to carbon number 8 as an upper end-point of the

suitable range of aromatic hydrocarbons, and the aromatic hydrocarbons can include higher carbon numbers, e.g., 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, and higher. In an embodiment, the aromatic hydrocarbons carbon number is as high as 22. In embodiments, at least a portion of the aromatics in the hydrocarbon stream **12** comprise at least a portion of the heavy hydrocarbon molecules.

[0030] In an embodiment, the hydrocarbon stream **12** comprises no aromatic hydrocarbons.

[0031] As discussed herein, embodiments of the processes disclosed herein contemplate hydrocracking of molecules, and in particular, heavy hydrocarbon molecules of the hydrocarbon stream **12**. As such, it is contemplated that at least a portion of the pyrolysis oils comprises heavy hydrocarbon molecules (e.g., also referred to as heavy ends of the pyrolysis oils). Hydrocracking of the heavy ends of the pyrolysis oils to meet steam cracker **40** specifications is contemplated. In an embodiment, the concentration of heavy hydrocarbon molecules in the hydrocarbon stream **12** may be less than 10 wt % based on the total weight of the hydrocarbon stream **12**. Alternatively, the concentration of the heavy hydrocarbon molecules in the hydrocarbon stream **12** may be 10 wt % to 90 wt % based on the total weight of the hydrocarbon stream **12**. As described above, the heavy hydrocarbon molecules may include paraffins, i-paraffins, olefins, naphthenes, aromatic hydrocarbons, or combinations thereof. In embodiments, the heavy hydrocarbon molecules may include C_{16} and larger hydrocarbons. Greater than 5, 10, 15, 20, 25, 30 wt % or more of the heavy hydrocarbon molecules in the hydrocarbon stream **12** is hydrocracked when the hydrocarbon stream **12** is contacted with the hydroprocessing catalyst in the hydroprocessing reactor **20**.

[0032] Chloride compounds which may be included in the hydrocarbon stream **12** include, but are not limited to, aliphatic chlorine-containing hydrocarbons, aromatic chlorine-containing hydrocarbons, and other chlorine-containing hydrocarbons. Examples of chlorine-containing hydrocarbons include, but are not limited to, 1-chlorohexane ($C_6H_{13}Cl$), 2-chloropentane ($C_5H_{11}Cl$), 3-chloro-3-methylpentane ($C_6H_{13}Cl$), (2-chloroethyl) benzene (C_8H_9Cl), chlorobenzene (C_6H_5Cl), or combinations thereof. The concentration of chloride compounds in the hydrocarbon stream **12** may be 5 ppm, 6 ppm, 7 ppm, 8 ppm, 9 ppm, 10 ppm, 15 ppm, 20 ppm, 30 ppm, 40 ppm, 50 ppm, 100 ppm, 200 ppm, 300 ppm, 400 ppm, 500 ppm, 600 ppm, 700 ppm, 800 ppm, 900 ppm, 1,000 ppm, 1,100 ppm, 1,200 ppm, 1,300 ppm, 1,400 ppm, 1,500 ppm, 1,600 ppm, 1,700 ppm, 1,800 ppm, 1,900 ppm, 2,000 ppm or more based on the total weight of the hydrocarbon stream **12**.

[0033] Sulphides which may be included in the hydrocarbon stream **12** include sulphur-containing compounds. For example, a sulphiding agent such as dimethyl disulphide ($C_2H_6S_2$), dimethyl sulphide (C_2H_6S), mercaptans ($R-SH$), carbon disulphide (CS_2), hydrogen sulphide (H_2S), or combinations thereof may be used as the sulphide in the hydrocarbon stream **12**.

[0034] In an embodiment, one or more sulphides (e.g., dimethyl disulphide ($C_2H_6S_2$), dimethyl sulphide (C_2H_6S), mercaptans ($R-SH$), carbon disulphide (CS_2), hydrogen sulphide (H_2S), or combinations thereof) are added to the hydrocarbon stream **12** (e.g., the hydrocarbon stream **12** is "spiked" with one or more sulphides), for example, via a spiking stream **14**, before the hydrocarbon stream **12** is intro-

duced to the hydroprocessing reactor **20**. In such embodiments, the one or more sulphides are added to the hydrocarbon stream **12** in an amount such that a sulphur content of the hydrocarbon stream **12**, after sulphide addition, is about 0.5 wt %, 1 wt %, 1.5 wt %, 2 wt %, 2.5 wt %, 3 wt %, 3.5 wt %, 4 wt %, 4.5 wt %, 5 wt % or more based on the total weight of the hydrocarbon stream **12**. In embodiments, the spiking stream **14** may include components tailored for spiking such as hexadecane and dimethyl disulphide; alternatively, the spiking stream **14** may be a heavier oil (e.g., naphtha, diesel, or both) which already contains sulphide compounds (or to which sulphides are spiked to achieve the sulphur content disclosed herein) and which is blended with the hydrocarbon stream **12** to achieve the sulphur content described above.

[0035] In alternative embodiments, one or more sulphides are present in the hydrocarbon stream as a result of upstream processing from which the hydrocarbon stream **12** flows. In such embodiments, the hydrocarbon stream **12** may contain one or more sulphides in an amount such that a sulphur content of the hydrocarbon stream **12**, without sulphide spiking, is about 0.5 wt %, 1 wt %, 1.5 wt %, 2 wt %, 2.5 wt %, 3 wt %, 3.5 wt %, 4 wt %, 4.5 wt %, 5 wt % or more based on the total weight of the hydrocarbon stream **12**.

[0036] In yet other embodiments, the hydrocarbon stream **12** may contain one or more sulphides in an amount insufficient for sulphiding (e.g., less than 5,000, 4,000, 3,000, 2,000, 1,000, 900, 800, 700, 600, 500, 400, 300, 200, 100, 90, 80, 70, 60, 50, 40, 30, 20, 10, 5, or 1 ppm) the hydroprocessing catalyst contained in the hydroprocessing reactor **20** (the catalyst is discussed in more detail below), and spiking stream **14** is utilized to raise the concentration of the one or more sulphides in the hydrocarbon stream to such that a sulphur content of the hydrocarbon stream **12**, after sulphide addition, is about 0.5 wt %, 1 wt %, 1.5 wt %, 2 wt %, 2.5 wt %, 3 wt %, 3.5 wt %, 4 wt %, 4.5 wt %, 5 wt % or more based on the total weight of the hydrocarbon stream **12**.

[0037] In an embodiment, the sulphur content of the hydrocarbon stream **12**, after sulphide addition using spiking stream **14**, is up to about 3 wt % based on the total weight of the hydrocarbon stream **12**. In another embodiment, the sulphur content of the hydrocarbon stream **12**, without sulphide addition using spiking stream **14**, is up to about 3 wt % based on the total weight of the hydrocarbon stream **12**.

[0038] The hydroprocessing reactor **20** is configured to dechlorinate, hydrogenate, and hydrocrack components of the hydrocarbon stream **12** fed to the hydroprocessing reactor **20**. In the hydroprocessing reactor **20**, the hydrocarbon stream **12** is contacted with the hydroprocessing catalyst in the presence of hydrogen to yield a hydrocarbon product in stream **22**. It is contemplated the hydrocarbon stream **12** may be contacted with the hydroprocessing catalyst in upward flow, downward flow, radial flow, or combinations thereof, with or without a staged addition of hydrocarbon stream **12**, spiking stream **14**, a H_2 stream **24**, or combinations thereof. It is further contemplated the components of the hydrocarbon stream **12** may be in the liquid phase, a liquid-vapor phase, or a vapor phase while in the hydroprocessing reactor **20**.

[0039] The hydroprocessing reactor **20** may facilitate any reaction of the components of the hydrocarbon stream **12** in the presence of, or with, hydrogen. Reactions may occur as the addition of hydrogen atoms to double bonds of unsaturated molecules (e.g., olefins, aromatic compounds), resulting in saturated molecules (e.g., paraffins, i-paraffins, naphthenes). Additionally, reactions in the hydroprocessing reac-

tor **20** may cause a rupture of a bond of an organic compound, resulting in “cracking” of a hydrocarbon molecule into two or more smaller hydrocarbon molecules, or resulting in a subsequent reaction and/or replacement of a heteroatom with hydrogen. Examples of reactions which may occur in the hydroprocessing reactor **20** include, but are not limited to, the hydrogenation of olefins, removal of heteroatoms from heteroatom-containing hydrocarbons (e.g., dechlorination), hydrocracking of large paraffins or i-paraffins to smaller hydrocarbon molecules, hydrocracking of aromatic hydrocarbons to smaller cyclic or acyclic hydrocarbons, conversion of one or more aromatic compounds to one or more cycloparaffins, isomerization of one or more normal paraffins to one or more i-paraffins, selective ring opening of one or more cycloparaffins to one or more i-paraffins, or combinations thereof.

[0040] In an embodiment, contacting the hydrocarbon stream **12** with the hydroprocessing catalyst in the presence of hydrogen yields a hydrocarbon product comprising C_1 to C_4 gases and C_5 +(C_5 and heavier) liquid hydrocarbons. As explained below, the separator **30** recovers the C_5 + liquid hydrocarbons in the treated hydrocarbon stream **32**. The C_1 to C_4 gases can be recovered in hydroprocessed light gas stream **36**.

[0041] In embodiments, the hydroprocessing reactor **20** may be any vessel configured to contain the hydroprocessing catalyst disclosed herein. The vessel may be configured for gas phase, liquid phase, vapor-liquid phase, or slurry phase operation. The hydroprocessing reactor **20** may include one or more beds of the hydroprocessing catalyst in fixed bed, fluidized bed, moving bed, ebullated bed, slurry bed, or combinations thereof, configuration. The hydroprocessing reactor **20** may be operated adiabatically, isothermally, nonadiabatically, non-isothermally, or combinations thereof. The reactions of this disclosure may be carried out in a single stage or in multiple stages. For example, the hydroprocessing reactor **20** can be two reactor vessels fluidly connected in series, each having one or more catalyst beds of the hydroprocessing catalyst. Alternatively, two or more stages for hydroprocessing may be contained in a single reactor vessel. In embodiments having multiple stages, the first stage may dechlorinate and hydrogenate components of the hydrocarbon stream **12** to yield a first hydrocarbon product having a first level of chloride compounds and olefins. The first hydrocarbon product may flow from the first stage to the second stage, where other components of the first hydrocarbon product are dechlorinated and hydrogenated to yield a second hydrocarbon product stream (stream **22** in FIG. 1) having a second level of chloride compounds and olefins. The second hydrocarbon stream may then be treated as described herein for stream **22**.

[0042] In an embodiment, the hydroprocessing reactor **20** may comprise one or more vessels.

[0043] In embodiments of a single vessel or multiple vessels, the sulphur present in the hydrocarbon stream **12** is removed as H_2S to provide a reduced level of sulphur acceptable for downstream processing in steam crackers and refinery units.

[0044] In an embodiment, hydrogen may feed to the hydroprocessing reactor **20** in stream **24**. The rate of hydrogen addition to the hydroprocessing reactor **20** is generally sufficient to achieve the hydrogen-to-hydrocarbon ratios disclosed herein.

[0045] The disclosed hydroprocessing reactor **20** may operate at various process conditions. For example, contact-

ing the hydrocarbon stream **12** with the hydroprocessing catalyst in the presence of hydrogen may occur in the hydroprocessing reactor **20** at a temperature of 100° C. to 450° C.; alternatively, 100° C. to 350° C.; or alternatively, 260° C. to 350° C. Contacting the hydrocarbon stream **12** with the hydroprocessing catalyst in the presence of hydrogen may occur in the hydroprocessing reactor **20** at a pressure of 1 barg to 200 barg; or alternatively, 20 barg to 60 barg. Contacting the hydrocarbon stream **12** with the hydroprocessing catalyst in the presence of hydrogen may occur in the hydroprocessing reactor **20** at a weight hourly space velocity (WHSV) of between 0.1 hr^{-1} to 10 hr^{-1} ; or alternatively, 1 hr^{-1} to 3 hr^{-1} . Contacting the hydrocarbon stream **12** with the hydroprocessing catalyst in the presence of hydrogen may occur in the hydroprocessing reactor **20** at a hydrogen-to-hydrocarbon (H_2/HC) flow ratio of 10 to 3,000 NL/L; or alternatively, 200 to 800 NL/L.

[0046] It is contemplated that dechlorination using the hydroprocessing catalyst as described herein is performed in the hydroprocessing reactor **20** without the use of chlorine sorbents, without addition of Na_2CO_3 in an effective amount to function as a dechlorinating agent, or both.

[0047] The hydroprocessing catalyst may be any catalyst used for hydrogenation (e.g., saturation) of olefins and aromatic hydrocarbons (e.g., a commercially available hydrotreating catalyst). In an embodiment, the hydroprocessing catalyst is a cobalt and molybdenum catalyst (Co—Mo catalyst) on an alumina support. In other embodiments, the hydroprocessing catalyst is a nickel and molybdenum catalyst (Ni—Mo catalyst) on an alumina support or tungsten and molybdenum catalyst (W—Mo catalyst) on an alumina support. Other catalyst embodiments may include platinum and palladium catalyst (Pt—Pd catalyst) on an alumina support, nickel sulphides suitable for slurry processing, molybdenum sulphides suitable for slurry processing, nickel and molybdenum sulphides, or combinations thereof.

[0048] In embodiments where the hydrocarbon stream **12** comprises one or more sulphides and one or more chloride compounds, contacting the hydrocarbon stream **12** with the hydroprocessing catalyst acts to activate the hydroprocessing catalyst by sulphiding and to acidify the hydroprocessing catalyst by chlorinating. Continuously contacting the hydroprocessing catalyst with the hydrocarbon stream **12** containing the one or more sulphides, the one or more chloride compounds, or both, may maintain the catalyst activity on a continuous basis.

[0049] In embodiments, the hydroprocessing catalyst is activated and/or the activity is maintained by sulphiding the hydroprocessing catalyst in-situ. For example, the hydroprocessing catalyst may be sulphided (i.e., activated) and/or sulphiding (i.e., maintaining the catalyst activity) of the hydroprocessing catalyst may be performed (e.g., maintaining the hydroprocessing catalyst in sulphided form is accomplished) by continuously contacting the hydrocarbon stream **12** containing one or more sulphides with the hydroprocessing catalyst. The one or more sulphides may be included in the hydrocarbon stream **12** in an amount such that the sulphur content of the hydrocarbon stream **12** is about 0.5 wt %, 1 wt %, 1.5 wt %, 2 wt %, 2.5 wt %, 3 wt %, 3.5 wt %, 4 wt %, 4.5 wt %, or 5 wt % based on the total weight of the hydrocarbon stream **12**.

[0050] Alternatively, the hydroprocessing catalyst may be sulphided (i.e., activated) by contacting a catalyst activating stream **26** containing one or more sulphides with the hydro-

processing catalyst for a period of time (e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9 or more hours) sufficient to activate the hydroprocessing catalyst (before contacting the hydrocarbon stream 12 with the hydroprocessing catalyst). In such embodiments, the catalyst activating stream 26 may include a hydrocarbon carrier for the one or more sulphides, such as hexadecane. The one or more sulphides may be included in the catalyst activating stream 26 in an amount such that the sulphur content of the catalyst activating stream 26 is about 0.5 wt %, 1 wt %, 1.5 wt %, 2 wt %, 2.5 wt %, 3 wt %, 3.5 wt %, 4 wt %, 4.5 wt %, 5 wt % or more based on the total weight of the catalyst activating stream 26. After the hydroprocessing catalyst is activated with the catalyst activating stream 26, flow of the catalyst activating stream 26 may be discontinued, and sulphiding (i.e., maintaining the catalyst activity) of the hydroprocessing catalyst may be maintained (e.g., maintaining the hydroprocessing catalyst in sulphided form is accomplished) by continuously contacting the hydrocarbon stream 12 containing one or more sulphides with the hydroprocessing catalyst. The one or more sulphides may be included in the hydrocarbon stream 12 in an amount such that the sulphur content of the hydrocarbon stream 12 is about 0.5 wt %, 1 wt %, 1.5 wt %, 2 wt %, 2.5 wt %, 3 wt %, 3.5 wt %, 4 wt %, 4.5 wt %, or 5 wt % based on the total weight of the hydrocarbon stream 12.

[0051] In embodiments, sulphiding and maintaining the catalyst in sulphided form may use two different concentrations of sulphur content in the hydrocarbon stream 12. For example, the one or more sulphides may be included (e.g., provided via spiking stream 14) in the hydrocarbon stream 12 in an amount such that the sulphur content of the hydrocarbon stream 12 is about 2 wt % based on the total weight of the hydrocarbon stream 12 for sulphiding, and the one or more sulphides may be maintained (e.g., via spiking stream 14) in the hydrocarbon stream 12 in an amount such that the sulphur content of the hydrocarbon stream 12 is about 2 wt % based on the total weight of the hydrocarbon stream 12 for maintaining the hydroprocessing catalyst in the sulphided form. In another example, the one or more sulphides may be included in the catalyst activating stream 26 in an amount such that the sulphur content of the catalyst activating stream 26 is about 3 wt % based on the total weight of the catalyst activating stream 26 for sulphiding, and the one or more sulphides may be included (e.g., via spiking stream 14) in the hydrocarbon stream 12 in an amount such that the sulphur content of the hydrocarbon stream 12 is about 2 wt % based on the total weight of the hydrocarbon stream 12 for maintaining the hydroprocessing catalyst in the sulphided form.

[0052] In embodiments, catalyst activity is also maintained by chloriding the hydroprocessing catalyst. The hydroprocessing catalyst is chlorided using the one or more chloride compounds provided to the hydroprocessing catalyst by the hydrocarbon stream 12. The one or more chloride compounds which contribute to acidification of the hydroprocessing catalyst may be included in the hydrocarbon stream 12 in concentrations disclosed herein.

[0053] Sulphiding and maintaining the hydroprocessing catalyst in sulphided form result in a hydroprocessing catalyst which has hydrogenation sites (sulphided metal) for hydrogenation of components of the hydrocarbon stream 12. Chloriding the hydroprocessing catalyst results in a hydroprocessing catalyst which has hydrocracking sites (chloride alumina) for hydrocracking components of the hydrocarbon stream 12.

[0054] Due to hydrogenation reactions in the hydroprocessing reactor 20, in embodiments, the hydrocarbon product

stream 22 may contain one or more olefins in a concentration of less than 1 wt % based on the total weight of the hydrocarbon product stream 22. It is also contemplated that the concentration of aromatic hydrocarbons in the hydrocarbon product stream 22 is less than the concentration of aromatic hydrocarbons in the hydrocarbon stream 12 due to hydrogenation of at least a portion of the aromatic hydrocarbons in the hydroprocessing reactor 20. For example, aromatic hydrocarbons may be present in the hydrocarbon product stream 22 in a concentration of less than 10, 9, 8, 7, 6, 5, 4, 3, 2, or 1 wt % based on the total weight of the hydrocarbon product stream 22.

[0055] The reaction product flows as effluent from the hydroprocessing reactor 20 in the hydrocarbon product stream 22 to the separator 30. Separator 30 may be any vessel which can recover a treated hydrocarbon stream 32 from the hydrocarbon product stream 22 which is fed to the separator 30. In embodiments, the treated hydrocarbon stream 32 may be recovered by separating a treated product (e.g., liquid product or gas product) from sulphur and chlorine-containing gas in the separator 30, and flowing the treated product in the treated hydrocarbon stream 32 from the separator 30.

[0056] In an embodiment, the separator 30 is a condenser which operates at conditions which condense a portion of the hydrocarbon product stream 22 into the treated product (e.g., liquid product or treated liquid product) while leaving sulphur and chlorine-containing compounds in the gas phase. The treated liquid product flows from the separator 30 in treated hydrocarbon stream 32, and the sulphur and chlorine-containing gas flows from the separator 30 via hydroprocessed light gas stream 36. In such embodiments, the treated liquid product may comprise $C_5+(C_5 \text{ and heavier})$ liquid hydrocarbons.

[0057] In another embodiment, the separator 30 is a scrubbing unit containing a caustic solution (e.g., a solution of sodium hydroxide in water) which removes (e.g., via reaction, adsorption, absorption, or combinations thereof) sulphur and chlorine-containing gases from the hydrocarbon product stream 22 to yield the treated product which flows from the separator 30 via treated hydrocarbon stream 32 while the C_1 to C_4 hydrocarbons and sulphur and chlorine-containing compounds are removed from the separator 30 via hydroprocessed light gas stream 36. In such embodiments, the treated liquid product may comprise $C_5+(C_5 \text{ and heavier})$ liquid hydrocarbons.

[0058] In yet another embodiment, the separator 30 is a condenser in communication with one or more stages of a gas-liquid separator, followed by a scrubbing unit containing a caustic solution. As described above, the condenser may operate at conditions which condense a portion of the hydrocarbon product stream 22 into a mid-treated product (e.g., liquid product or treated liquid product) while leaving sulphur and chlorine-containing compounds in the gas phase which then flow into the scrubbing unit to provide a sulphur-free and chlorine-free stream of C_1 to C_4 hydrocarbon gases. In such embodiments, the mid-treated product may comprise $C_5+(C_5 \text{ and heavier})$ liquid hydrocarbons. The mid-treated liquid product flows from the condenser to the one or more stages of gas-liquid separator and experiences a pressure reduction (e.g., via a valve or other pressure reducing device known in the art with the aid of this disclosure) which creates an effluent gas (e.g., via flashing) which flows to the scrubbing unit from the one or more stages of gas-liquid separator for further removal of sulphur and chlorine-containing com-

pounds from the liquid hydrocarbons. The treated product flowing in treated hydrocarbon stream 32 flows from the final/last stage of the gas-liquid separator of the separator 30 to the steam cracker 40 via stream 32. Sulphur and chlorine-containing compounds in the gas products are scrubbed in the scrubbing unit of the separator 30 and flow from the separator 30 in hydroprocessed light gas stream 36.

[0059] In embodiments disclosed herein, no hydrogen halides and no halogenated organic compounds are recycled to the hydroprocessing reactor 20.

[0060] In embodiments, the treated hydrocarbon stream 32 includes one or more chloride compounds in a concentration of less than 5 ppm, 4 ppm, 3 ppm, 2 ppm, 1 ppm, or 0.5 ppm based on a total weight of the treated hydrocarbon stream 32. It is contemplated that the one or more chloride compounds in the treated hydrocarbon stream 32 may be the same as some or all of the one or more chloride compounds in the hydrocarbon stream 12; alternatively, it is contemplated that only some of the one or more chloride compounds in the treated hydrocarbon stream 32 are the same as only some of the one or more chloride compounds in the hydrocarbon stream 12; alternatively, it is contemplated that none of the one or more chloride compounds in the treated hydrocarbon stream 32 are the same as the one or more chloride compounds in the hydrocarbon stream 12.

[0061] In additional embodiments, the treated hydrocarbon stream 32 includes the one or more olefins in a concentration which is less than a concentration of the one or more olefins in the hydrocarbon stream 12 due to hydrogenation of at least a portion of the one or more olefins from the hydrocarbon stream 12 while the hydrocarbon stream 12 is contacted with the hydroprocessing catalyst in the hydroprocessing reactor 20. In yet additional embodiments, the treated hydrocarbon stream 32 includes the one or more olefins in a concentration which is less than a concentration of the one or more olefins in the hydrocarbon stream 12 due to hydrogenation and hydrocracking of at least a portion of the one or more olefins from the hydrocarbon stream 12 while the hydrocarbon stream 12 is contacted with the hydroprocessing catalyst in the hydroprocessing reactor 20. In an embodiment, the one or more olefins are present in the treated hydrocarbon stream 32 in a concentration of less than 1 wt % based on the total weight of the treated hydrocarbon stream 32.

[0062] In embodiments, the treated hydrocarbon stream 32 includes one or more paraffins, and the concentration of the one or more olefins is less than 1 wt % based on the total weight of the treated hydrocarbon stream 32. It is also contemplated that the concentration of aromatic hydrocarbons in the treated hydrocarbon stream 32 is less than the concentration of aromatic hydrocarbons in the hydrocarbon stream 12 due to hydrogenation of at least a portion of the aromatic hydrocarbons in the hydroprocessing reactor 20. For example, aromatic hydrocarbons may be present in the treated hydrocarbon stream 32 in a concentration of less than 10, 9, 8, 7, 6, 5, 4, 3, 2, or 1 wt % based on the total weight of the treated hydrocarbon product stream 32.

[0063] In embodiments, the treated hydrocarbon stream 32 may have a reduced concentration of heavy hydrocarbon molecules compared to the concentration of heavy hydrocarbon molecules in the hydrocarbon stream 12 due to hydrocracking of at least a portion of the heavy hydrocarbon molecules from the hydrocarbon stream 12 while the hydrocarbon stream 12 is contacted with the hydroprocessing catalyst. In further embodiments, the treated hydrocarbon

stream 32 may comprise none of the heavy hydrocarbon molecules from the hydrocarbon stream 12 due to hydrocracking of the heavy hydrocarbon molecules in the hydroprocessing reactor 20. Due to hydrocracking of heavy hydrocarbon molecules when the hydrocarbon stream 12 is contacted with the hydroprocessing catalyst in the hydroprocessing reactor 20, the treated hydrocarbon stream 32 may have a boiling end point of 370° C.

In embodiments where the treated hydrocarbon stream 32 includes one or more chloride compounds in a concentration of less than 3 ppm, the treated hydrocarbon stream 32 may be fed directly to the steam cracker 40. In alternative embodiments where the treated hydrocarbon stream 32 includes one or more chloride compounds in a concentration of 3 ppm or more (e.g., 3 ppm to 5 ppm), the treated hydrocarbon stream 32 may be blended with a non-chlorinated hydrocarbon stream 34 to yield a blended hydrocarbon stream 38 (streams 34 and 38 having dashed lines to denote the alternative embodiment) having a concentration of one or more chlorides which is less than 3 ppm based on a total weight of the blended hydrocarbon stream 38. The blended hydrocarbon stream 38 may be fed to the steam cracker 40.

[0064] Steam cracker 40 generally has feed specification requirements. First, the steam cracker 40 requires the concentration of chloride compounds in the feed to the steam cracker 40 to be less than 3 ppm. Second, the steam cracker 40 requires the concentration of olefins in a stream fed to the steam cracker 40 to be less than 1 wt %. Third, the steam cracker 40 requires the boiling end point of the stream fed to the steam cracker 40 to be 370° C. The steam cracker 40 cracks molecules or cleaves at elevated temperatures carbon-carbon bonds of the components in the treated hydrocarbon stream 32 or blended hydrocarbon stream 38 in the presence of steam to yield high value products such as ethylene, propylene, butene, butadiene, aromatic compounds, or combinations thereof. Likewise, in embodiments having light gas streams 16 and/or 28, the steam cracker 40 cracks molecules or cleaves at elevated temperatures carbon-carbon bonds of the components in the treated light gas product (e.g., of treated pyrolysis light gas stream 52 and/or treated hydroprocessed light gas stream 54) in the presence of steam to yield high value products such as ethylene, propylene, butene, butadiene, aromatic compounds, or combinations thereof. The high value products may flow from the steam cracker 40 via stream 42.

[0065] The pyrolysis gases in the pyrolysis light gas stream 16, the C₁ to C₄ gases in the hydroprocessed light gas stream 36, or both may flow to a scrubbing unit 50. The scrubbing unit 50 may be the same scrubbing unit used in embodiments of the separator 30 which include a scrubbing unit, or the scrubbing unit 50 may be in addition to any scrubbing unit included in the separator 30. As described for the scrubbing unit of the separator 30, the scrubbing unit 50 may contain a caustic solution (e.g., a solution of sodium hydroxide in water) which removes (e.g., via reaction, adsorption, absorption, or combinations thereof) sulphur and chlorine-containing gases from the stream (e.g., pyrolysis light gas stream 16 and/or hydroprocessed light gas stream 36) fed to the scrubbing unit 50 and yield a treated light gas product (e.g., treated pyrolysis light gas stream 52, treated hydroprocessed light gas stream 54, or a single treated light gas stream which combines the treated hydroprocessed product and treated pyrolysis product) which flows from the scrubbing unit 50 to

the steam cracker **40**. The removed compounds (sulphur and/or chlorine containing gases) may flow from the scrubbing unit **50** in stream **56**.

[0066] In embodiments utilizing scrubbing unit **50**, the treated pyrolysis light gas stream **52** may include one or more sulphide and/or chloride compounds in a concentration of less than 5 ppm, 4 ppm, 3 ppm, 2 ppm, 1 ppm, or 0.5 ppm based on a total weight of the treated pyrolysis light gas stream **52**.

[0067] In embodiments utilizing scrubbing unit **50**, the treated hydroprocessed light gas stream **54** may include one or more sulphide and/or chloride compounds in a concentration of less than 5 ppm, 4 ppm, 3 ppm, 2 ppm, 1 ppm, or 0.5 ppm based on a total weight of the treated hydroprocessed light gas stream **54**.

[0068] The foregoing describes a system **100** which implements one or more embodiments of an integrated process for the conversion of waste plastics to high value products. The integrated processes allow for operation with a single hydroprocessing reactor **20** which provides simultaneous hydrogenation, dechlorination, and hydrocracking of components of a hydrocarbon stream **12** to specifications which meet steam cracker **40** requirements.

[0069] Examples provided below demonstrate the various embodiments of the pyrolysis process for generating a pyrolysis oil or hydrocarbon stream, not limited by the equipment used. These examples are for high severity pyrolysis process carried out at temperatures of 450° C. to 750° C., low severity pyrolysis process carried out at 300° C. to 450° C., hydrogen or hydrogen donor assisted (hydropyrolysis) processes carried out at both the above severities as well as use of a catalyst recipe and a combination of sand and catalyst as a catalyst recipe. Though these examples are provided for fluidized beds where in the heat transfer and catalyst/feed contact are good, directionally the same type of results can be obtained with other types of pyrolysis equipment as described herein.

[0070] Also, as is demonstrated in the examples below and discussed above, it has been found that hydrocracking of olefins and heavy hydrocarbon molecules contained in a hydrocarbon stream occurs using a hydroprocessing catalyst at the conditions disclosed herein. The olefins are hydrogenated in addition to being hydrocracked. Moreover, chloride compounds contained in the hydrocarbon stream are removed. In embodiments, simultaneous hydrogenation, dechlorination, and hydrocracking of a hydrocarbon stream components is achieved in a single hydroprocessing step, with the treated hydrocarbon product being capable of feeding to a steam cracker having the feed requirements specified herein, without further separations or fractionations of the treated hydrocarbon product. In embodiments, simultaneous hydrogenation, dechlorination, and hydrocracking is achieved by continuously contacting a hydrocarbon stream having one or more sulphides and one or more chloride compounds at the concentrations disclosed herein with the hydroprocessing catalyst in the presence of hydrogen at the operating conditions disclosed herein. That is, catalyst activity can be initiated and/or maintained simultaneously with the simultaneous hydrogenation, dechlorination, and hydrocracking by using hydrocarbon streams of the compositions disclosed herein which feed to a hydroprocessing reactor.

[0071] Hydrocracking according to the embodiments disclosed herein can occur over the operating pressures disclosed herein for hydroprocessing reactor **20**, including those

low pressures demonstrated in the examples. Embodiments of the processes disclosed herein meet the feed boiling end point of 370° C. required for steam crackers. Moreover, the disclosed embodiments demonstrate that about 30 wt % of the heavy hydrocarbon molecules of a hydrocarbon stream can undergo hydrocracking at the conditions disclosed herein. When the hydrocarbon stream contains plastic and/or tire pyrolysis oil, the heavier ends of the pyrolysis oil are hydrocracked. Increased levels of paraffins due to the hydrocracking ability of the processes disclosed herein can result in a higher production of propylene in steam crackers. LPG gases are not liberated in the disclosed processes until the temperature of the one or more catalyst beds in the hydroprocessing reactor **20** reaches about 400° C. Gas product formation is minimized, which is useful for existing plants which are constrained on the gas flow rate to the gas compressor section. In the disclosed embodiments, the production of methane and ethane is also low.

[0072] Dechlorination according to the embodiments disclosed herein can occur over the operating temperature ranges disclosed herein for the hydroprocessing reactor **20**, including operating temperatures in the low-end of the temperature ranges disclosed herein. Removal of chloride compounds to less than 1 ppm occurs at temperatures below 350° C. Moreover, achieving sub-ppm chloride compound concentrations is possible with initial chloride content in the hydrocarbon stream **12** of 1,000 ppm or more. Moreover still, removal of chloride compounds is effective for different types and classes of chlorides present in the hydrocarbon stream **12**. When the hydroprocessing reaction is conducted at temperatures at or above 350° C., it has been found that the treated hydrocarbon product contains 3 ppm or higher chloride content. In such cases, the treated hydrocarbon product stream can be blended as described herein with a non-chlorinated stream **34** in such proportions to make the combined blended hydrocarbon stream **38** meet the steam cracker feed specifications.

[0073] Operation at low temperatures (e.g., less than 350° C.) also has an added advantage of corrosion mitigation of the reactor metallurgy. For most metals and alloys used in the commercial reactors, corrosion rates start to increase at reactor temperatures over 300° C. It has been found that the efficiency of dechlorination according to the disclosed embodiments is good at reactor temperatures below 350° C., and the dechlorination process works with a sulphided Co—Mo catalyst on an alumina support even as low as 260° C., with the chlorides in the treated product being less than 1 ppm. Thus, the metallurgy corrosion issue is mitigated and longer equipment life is possible while achieving dechlorination to levels desirable for feed to steam cracker **40**. The processes disclosed herein have been demonstrated to work at pressures as low as 20 barg, which is a less severe condition than the conditions typically employed with a commercial hydrotreating catalyst. Ability to operate at lower pressures reduces the required pressure rating for process vessels (e.g., the hydroprocessing reactor **20**) and provides an opportunity for reduced investment costs.

[0074] The disclosed embodiments also demonstrate olefins in the hydrocarbon product are reduced typically to less than 1 wt % of the treated hydrocarbon stream **32** from a feed olefin concentration of 20 wt % or more in the hydrocarbon stream **12**.

[0075] Thus, the disclosed embodiments achieve the pyrolysis of plastics and also the requirements of chloride content, olefin content, and boiling end point of the feed for a steam cracker.

EXAMPLES

[0076] The subject matter having been generally described, the following examples are given as particular embodiments of the disclosure and to demonstrate the practice and advantages thereof. It is understood that the examples are given by way of illustration and are not intended to limit the specification of the claims to follow in any manner.

[0077] Examples 1 to 6 were conducted in a fixed bed reactor located inside a 3-zone split-tube furnace. The reactor internal diameter was 13.8 mm and had concentrically located bed thermowell of 3 mm outer diameter. The reactor was 48.6 cm long. Commercial hydroprocessing catalyst of Co—Mo on alumina (8 g bone dry weight) was broken along the length to particles of 1.5 mm long and diluted with SiC in the ratio of 60% SiC to 40% catalyst to give a mean particle diameter of 0.34 mm. This was done to avoid slip through of the chlorides due to wall slip or channeling in the small diameter reactor. Pre-heating bed and post-catalyst inert beds was provided in the form of 1 mm glass beads. The catalyst bed temperature was controlled to isothermal by varying the controlled furnace zone skin temperatures. The catalyst was sulphided using 3 wt % S in hexadecane (S was introduced as dimethyl disulphide). Liquid feed (i.e., the hydrocarbon stream) was fed through a metering pump and H₂ gas was fed using a mass flow controller. The reactor effluent (i.e., the hydrocarbon product) gases were cooled to condense out the liquids (i.e., the treated hydrocarbon stream in the form of a liquid product) under pressure while allowing non-condensed gases (e.g., containing chloride(s), chlorine, hydrogen sulphide, or combinations thereof) to separate. Following liquid condensation, the pressure of the liquids was reduced and effluent gas flow was measured using a drum-type wet gas meter. The effluent gas flow was analyzed using a refinery gas analyzer (a custom gas analyzer from M/s AC Analyticals BV). The liquid product olefin content was determined using a Detailed Hydrocarbon Analyzer GC (DHA) and a boiling point characterization was obtained using a SIMDIS GC. The liquid product chloride content was measured using a Chlora M-series analyzer (monochromatic wavelength dispersive X-ray Fluorescence technique, ASTM D7536).

Example 1

[0078] In Example 1, a hydrocarbon feed mixture was prepared by mixing 30 wt % n-hexadecane, 10 wt % i-octane, 20 wt % 1-decene, 20 wt % cyclohexane, and 20 wt % ethyl benzene. Dimethyl disulphide, 2-chloropentane, 3-chloro-3-

methyl pentane, 1-chlorohexane, (2-chloroethyl) benzene, and chlorobenzene were then added to give 205 ppm organic chlorides and a sulphur content of 2 wt % S in the combined feed mixture. This combined feed mixture was used as the hydrocarbon stream which was contacted with the hydroprocessing catalyst in the packed bed reactor as mentioned above in the presence of H₂ at conditions of 280° C. reactor temperature, 60 barg reactor pressure, 0.92 hr⁻¹ WHSV, and 414 NL/L H₂/HC flow ratio. The liquid product (i.e., the treated hydrocarbon stream) was analyzed in a DHA wherein molecules lighter than C₁₃ are injected into the GC column and heavier than C₁₃ are flushed out. The normalized composition of liquid product as measured by DHA was paraffins (26.24 wt %), i-paraffins (17.28 wt %), olefins (0 wt %), naphthenes (33.61 wt %), and aromatics (22.88 wt %). SIMDIS analysis of liquid product indicates that 78 wt % of the liquid product boils at 180° C., and immediately at 79 wt %, the boiling point shifts to 286° C.; indicating that 22 wt % (i.e. 100–78=22) of the liquid product is hexadecane. This implies out of 30 wt % hexadecane in the feed (calculated based on the feed excluding chloride and sulphides, since dimethyl disulphide is converted to gases, the chloride compounds are dechlorinated so as to contribute less than 0.5 wt % of the product), 8 wt % of hexadecane was hydrocracked to lower products. As mentioned before, this 22 wt % does not get analyzed in DHA. This 22 wt % hexadecane unaccounted in DHA composition is added to the liquid product analyzed by DHA (DHA composition multiplied by 0.78 fraction that was injected into DHA) and the resulting composition of the liquid product is 42.47 wt % paraffins, 13.48 wt % i-paraffins, 0 wt % olefins, 26.21 wt % naphthenes and 17.84 wt % aromatics. In addition, the chloride content of the liquid product was 0.09 ppmw.

[0079] Example 1 demonstrates it is possible to simultaneously dechlorinate, hydrogenate, and hydrocrack a PIONA hydrocarbon stream containing heavy hydrocarbon molecules (e.g., hexadecane), a chloride content of more than 200 ppm, and an olefin content of 20 wt % (calculated based on the feed excluding chloride and sulphides) such that a portion of the heavy hydrocarbon molecules are hydrocracked, chloride content is reduced to less than 1 ppm, and olefins are completely removed (0 wt % in the liquid product). Comparing feed and liquid product compositions, it can be said that paraffins, i-paraffins, and naphthenes have increased in concentration, while aromatics have reduced in concentration and olefins were completely depleted. This clearly indicates hydrocracking of hexadecane as well as hydrocracking of olefins in feed. Thus, Example 1 additionally demonstrates olefins are hydrocracked in addition to being hydrogenated.

[0080] The DHA analysis summary by carbon number for the liquid product is shown below:

Carbon No.	n-Paraffins, wt %	i-Paraffins, wt %	Olefins, wt %	Naphthenes, wt %	Aromatics, wt %	Total, wt %
2						
3						
4		0.015				0.015
5	0.012					0.012
6	0.016	0.18		27.136	0.048	27.217
7						0
8	0.145	14.226		0.547	21.979	36.896

-continued

Carbon No.	n-Paraffins, wt %	i-Paraffins, wt %	Olefins, wt %	Naphthenes, wt %	Aromatics, wt %	Total, wt %
9		0.079		5.901	0.834	6.814
10	26.01	2.93				0.039
11						
12						
Total, wt %	26.221	17.268		35.584	22.86	99.933
Unknown						0.053
Heavies						0.013

Example 2

[0081] Example 2 explores the effect of operating pressure on hydrocracking performance. A hydrocarbon feed mixture was prepared by mixing 30 wt % n-hexadecane, 10 wt % i-octane, 20 wt % 1-decene, 20 wt % cyclohexane, and 20 wt % ethyl benzene. Dimethyl disulphide, 2-chloropentane, 3-chloro-3-methyl pentane, 1-chlorohexane, (2-chloroethyl) benzene, and chlorobenzene were then added to give 205 ppm organic chlorides and a sulphur content of 2 wt % S in the combined feed mixture. This combined feed mixture was used as a hydrocarbon stream which was contacted with the sulphided hydroprocessing catalyst in the packed bed reactor as mentioned above in the presence of H₂ at conditions of 300° C. reactor temperature, 0.92 hr⁻¹ WHSV, and 414 NL/L H₂/HC flow ratio. Three different pressure conditions were studied: 60 barg for Example 2A, 20 barg for Example 2B, and 10 barg for Example 2C. The liquid products (i.e., the treated hydrocarbon streams) for each of Examples 2A to 2C were analyzed using SIMDIS, and the results are shown below:

Example 2A Liquid Product 60 barg		Example 2B Liquid Product 20 barg		Example 2C Liquid Product 10 barg	
Cut, wt %	T, ° C.	Cut, wt %	T, ° C.	Cut, wt %	T, ° C.
0	61.4	0	52.0	0	61.4
5	72.0	5	61.4	5	72.0
10	72.0	10	72.0	10	72.0
15	72.0	15	72.0	15	72.0
20	72.0	20	72.0	20	72.0
25	72.0	25	72.0	25	72.0
30	87.6	30	72.0	30	72.0
35	87.6	35	72.0	35	87.6
40	87.6	40	87.6	40	87.6
45	87.6	45	87.6	45	132.0
50	87.6	50	134.6	50	137.2
55	129.4	55	137.2	55	139.8
60	134.6	60	139.8	60	139.8
65	139.8	65	142.4	65	161.2
70	170.6	70	163.2	70	173.8
75	176.0	75	175.4	75	177.0
79	177.6	80	179.0	78	178.0
80	278.6	83	180.6	80	271.6
85	289.2	85	279.6	85	288.2
90	292.0	90	291.0	90	291.6
95	294.0	95	294.6	95	294.0
99	295.4	99	296.8	99	295.4
100	295.6	100	297.0	100	295.6

[0082] The DHA analysis summary of the liquid product boiling below 240° C. is shown below:

Example No.	n-Paraffins, wt %	i-Paraffins, wt %	Olefins, wt %	Naphthenes, wt %	Aromatics, wt %	Unknown, wt %	Heavies, wt %
2A	22.507	19.415	0.183	31.159	17.912	0.131	0.693
2B	19.544	21.513	0.047	30.490	27.465	0.315	0.626
2C	21.368	21.281	0.000	24.687	30.719	0.355	1.591

[0083] The results provided in the tables above indicate that 20 wt % or less of the liquid product for each of Examples 2A to 2C boils in the hexadecane boiling point range. In contrast, the feed contained 30 wt % hexadecane (calculated based on the feed excluding chlorides and sulphides). Hence, at all pressures, hydrocracking of heavy hydrocarbon molecules (e.g., hexadecane) using a hydrogenation catalyst is demonstrated.

[0084] The corresponding chloride contents of the liquid product (i.e., treated hydrocarbon stream) at 60 barg, 20 barg, and 10 barg were respectively 0.11 ppmw, 0.09 ppmw, and 0.12 ppmw.

[0085] The liquid product (analyzed in DHA) for Example 2A (60 barg) contained 0.183 wt % olefins, for Example 2B (20 barg) contained 0.047 wt %, and for Example 2C (10 barg) contained 0 wt % olefins. At lower pressures, a significant increase in aromatics is observed.

[0086] Example 2 demonstrates it is possible to simultaneously dechlorinate and hydrocrack a PIONA hydrocarbon stream containing heavy hydrocarbon molecules (e.g., hexadecane) and a chloride content of more than 200 ppmw such that a portion of the heavy hydrocarbon molecules are hydrocracked and chloride content is reduced to less than 1 ppmw for all pressures tested.

Example 3

[0087] In Example 3, a hydrocarbon feed mixture was prepared to contain 30 wt % n-hexadecane, 10 wt % i-octane, 20 wt % 1-decene, 20 wt % cyclohexane and 20 wt % ethyl benzene. To this the organic chlorides mentioned in Example 2 above were added along with dimethyl disulphide to give 205 ppm organic chlorides and 2 wt % S in the mixture. This feed was used as a hydrocarbon stream which was contacted with the sulphided hydroprocessing catalyst in the packed bed reactor as mentioned above in the presence of H₂ at conditions of 260° C. reactor temperature, 60 barg reactor pressure, 0.92 hr⁻¹ WHSV and 414 NL/L H₂/HC flow ratio. The liquid product (i.e., the treated hydrocarbon stream) contained 0.1 ppmw chloride.

[0088] Example 3 demonstrates the effective removal of chloride compounds from a hydrocarbon stream at very low temperatures.

Example 4

[0089] In Example 4, a feed was prepared by mixing plastic pyrolysis oil (36.3 g) with n-hexadecane (240 g), and then adding dimethyl disulphide (the sulphide) and 1-chlorohexane (the chloride compound) to give a sulphur content of 2.34 wt % and 836 ppmw chloride in the feed. This feed was used as a hydrocarbon stream which was contacted with the hydroprocessing catalyst in the packed bed reactor as mentioned above in the presence of H₂ under several operating conditions as provided in the table below:

T, ° C.	P, barg	WHSV, hr ⁻¹	H ₂ /HC, NL/L	Cl, ppm in liquid product
300	60	0.92	414	0.32
300	40	0.92	414	0.87
350	40	0.92	414	3.42
400	40	0.92	414	3.15

[0090] Example 4 demonstrates it is possible to dechlorinate a hydrocarbon stream containing plastic pyrolysis oil and having chloride compounds from a chloride content of more than 800 ppmw chlorides to less than 5 ppmw in the liquid product. As can be seen from the above table, the chloride content of the liquid product (i.e., the treated hydrocarbon stream) increases when the reactor bed temperature is increased to at or above 350° C. At temperatures below 350° C., Example 4 demonstrates removal of chloride compounds to chloride contents less than 3 ppmw, and even sub-ppm levels.

Example 5

[0091] In Example 5, a hydrocarbon feed mixture was prepared by mixing 30 wt % n-hexadecane, 10 wt % i-octane, 20 wt % 1-decene, 20 wt % cyclohexane, and 20 wt % ethyl benzene. Dimethyl disulphide, 2-chloropentane, 3-chloro-3-methyl pentane, 1-chlorohexane, (2-chloroethyl) benzene, and chlorobenzene were then added to give 1,100 ppmw organic chlorides and a sulphur content of 2 wt % S in the combined feed mixture. This combined feed mixture was used as the hydrocarbon stream which was contacted with the hydrogenating catalyst in the packed bed reactor as mentioned above in the presence of H₂ at conditions of 300° C. reactor temperature, 40 barg reactor pressure, 0.92 hr⁻¹ WHSV, and 414 NL/L H₂/HC flow ratio. The liquid product contained 0.23 ppmw chlorides and paraffins of 22.569 wt %, i-paraffins of 19.752 wt %, olefins of 0.114 wt %, naphthenes of 33.242 wt %, aromatics of 23.7 wt %, unknowns of 0.16 wt % and heavies of 0.463 wt % as per DHA analysis. This again demonstrates the dechlorination of liquid at much higher chloride concentrations.

[0092] The SIMDIS of liquid product resulted in the following distribution and also indicated hydrocracking:

Cut, wt %	T, ° C.
0	61.4
5	72
10	72
15	72
20	72
25	72
30	72
35	72
40	87.6
45	87.6
50	132
55	134.6
60	137.2
65	142.4
70	170.6
75	175.4
80	177
85	287
90	290
95	292.2
99	293.4
100	293.8

[0093] DHA Group type analysis of the liquid product by carbon number (in wt %) is as below:

Carbon No.	n-Paraffins, wt %	i-Paraffins, wt %	Olefins, wt %	Naphthenes, wt %	Aromatics, wt %	Total, wt %
2						0
3						0
4	0.008	0.056				0.064
5	0.033	0.021				0.054
6	0.035	0.05		26.925	0.072	27.082
7	0.013	0.008		0.012		0.033
8	0.287	13.892		0.951	21.97	37.1
9		0.172	0.114	5.265	1.623	7.174
10	22.161	5.553		0.089	0.035	27.838
11	0.025					0.025
12	0.007					0.007
Oxygenates						
Heavies						0.464
Unknown						0.16
Total, wt %						100.001

[0094] In this example, the yield of liquid products was 95.5 wt % of the total products. The balance was gas products.

Example 6

[0095] In Example 6, a n-hexadecane feed mixture was prepared by mixing n-hexadecane with dimethyl disulphide, 2-chloropentane, 3-chloro-3-methyl pentane, 1-chlorohexane, (2-chloroethyl) benzene, and chlorobenzene to give 1,034 ppmw of chlorides and 2 wt % Sulphur in the feed. This combined feed mixture was used as the hydrocarbon stream which was contacted with the hydrogenating catalyst in the packed bed reactor as mentioned above in the presence of H₂ at conditions of 300° C. reactor temperature, 40 barg reactor pressure, 0.92 hr⁻¹ WHSV, and 414 NL/L H₂/HC flow ratio. The liquid product contained 0.3 ppmw chlorides and paraffins of 22.569 wt %, i-paraffins of 19.752 wt %, olefins of 0.114 wt %, naphthenes of 33.242 wt %, aromatics of 23.7 wt %, unknowns of 0.16 wt % and heavies of 0.463 wt % as per DHA analysis. This again demonstrates the dechlorination of liquid at high chloride concentrations to sub-ppm levels.

[0096] The SIMDIS of liquid product resulted in the following distribution and also indicated hydrocracking to the extent of about 15 wt % on a chloride and sulphide-free feed basis:

Cut, wt %	T, ° C.
0	61.4
5	129.4
10	161.2
13	170.6
14	260.2
15	272.4
20	285.2
25	287.4
30	289
35	290.2
40	291.2
45	292.2
50	293
55	293.8
60	294.4
65	295
70	295.6
75	296.2
80	297
85	297.4
90	297.8
95	298.2
99	298.8
100	310.8

[0097] DHA Group type analysis of the liquid product by carbon number (in wt %) is as below and indicates conversion of n-hexadecane to various PIONA components:

Carbon No.	n-Paraffins, wt %	i-Paraffins, wt %	Olefins, wt %	Naphthenes, wt %	Aromatics, wt %	Total, wt %
2	0.005					0.005
3	0.006					0.006
4	0.019	0.098				0.118
5	0.068	0.064				0.132
6	0.072	0.133		25.607	0.11	25.922
7	0.016	0.034				0.051
8	0.401	13.31		1.268	21.179	36.157
9		0.133	0.136	5.53	2.449	8.248

-continued

Carbon No.	n-Paraffins, wt %	i-Paraffins, wt %	Olefins, wt %	Naphthenes, wt %	Aromatics, wt %	Total, wt %
10	19.165	8.19		0.213	0.049	27.617
11	0.03					0.03
12	0.011					0.011
Oxygenates						
Heavies						1.413
Unknown						0.29
Total, wt %						100

Example 7

[0098] Example 7 shows a high severity operation for the pyrolysis unit **10**. An amount of 1.5 g of plastics feed and 9 g of catalyst mixture having a composition comprised of 37.5 wt. % ZSM-5 catalyst, with the remainder being spent FCC

light gas olefins, i.e., the sum of yields of ethylene, propylene and butenes was 32.69 wt %, and the total yield of gas products was 45.17 wt %.

[0100] The DHA analysis of the liquid product boiling below 240° C. was:

Carbon No.	n-Paraffins, wt %	i-Paraffins, wt %	Olefins, wt %	Naphthenes, wt %	Aromatics, wt %	Total, wt %
5	0.013	0.02	0.169	0.031		0.233
6	0.101	0.219	1.031	0.318	5.28	9.113
7	0.254	1.243	2.267	0.665	17.188	21.618
8	0.544	2.703	0.354	1.125	30.339	35.066
9	0.22	3.98	0.107	1.44	10.95	16.70
10	0.12	2.07		0.217	3.89	6.30
11	0.10	2.53		0.299	1.53	4.39
12	0.05	0.46			3.37	3.88
13	0.03					0.03
Unknown						2.69
Total, wt %	1.42	13.22	3.928	4.03	74.72	97.32
Total, wt % on Aromatics-Free Basis	6.3	58.5	17.4	17.8		100

catalyst, were used in pyrolysis conversions in a fluidized bed reactor. Details regarding the experimental facility for Example 7 are described in U.S. Patent Publication No. 2014/0228606A1, which is incorporated herein by reference in its entirety. The mixed plastics feed had the following composition:

Material	Amount, wt %
HDPE	19
LDPE	21
PP	24
C ₄ -LLDPE	12
C ₆ -LLDPE	6
PS	11
PET	7

[0099] The reaction temperature at start of reaction was 670° C. The one-minute average bed temperatures achieved was 569.6° C. The Catalyst/Feed (C/F) ratio was 6. Fluidization N₂ gas flow rate used was 175N cc/min. Overall aromatic and liquid i-paraffin product yields in liquid product boiling below 240° C. were 31.6 wt % and 5.76 wt %, respectively. Their respective concentrations in the liquid product boiling below 240° C. was 74.72 wt % and 13.22 wt %. The yield of

[0101] The yield of heavy products boiling above 370° C. was 0.86 wt %.

Example 8

[0102] Example 8 shows a high severity operation for the pyrolysis unit **10**, operated in a hydrogen-assisted hydro-pyrolysis mode. An amount of 1.5 g of mixed plastics was mixed with 9 g of a catalyst mixture comprising 62.5 wt % spent FCC catalyst and 37.5 wt % ZSM-5 zeolite catalyst. The combined mixture was then fed to the fluidized bed reactor described in Example 7 above. The plastic feed was in the form of a 200 micron plastic powder. A mixture of 10% H₂ in N₂ was employed as the carrier gas at a flow rate of 175 N cc/min.

[0103] Studies were conducted by maintaining the reactor bed temperature, before feed and catalyst mixture was introduced, at 600° C., 635° C., and 670° C., respectively, i.e., at 3 different starting temperatures. Studies were also conducted at the same conditions as before with 100% N₂ as carrier gas. For each of the temperature conditions studied, a new set of catalyst and feed mixture was prepared and used.

[0104] The tables below summarize the experimental findings, where all study used a mixed plastic feed and spent FCC (62.50 wt %)+ZSM-5 zeolite catalyst (37.5 wt %) as the pyrolysis catalyst:

	Hydro- pyrolysis 1	Pyrolysis 1	Hydro- pyrolysis 2	Pyrolysis 2	Hydro- pyrolysis 3	Pyrolysis 3
Feed Weight Transferred, g	1.50	1.50	1.50	1.50	1.50	1.50
Bone-Dry Catalyst Feed, g	9.05	8.95	9.05	9.05	9.01	8.95
C/F ratio, g/g	6.03	6.0	6.03	6.03	6.00	6.0
Reaction Start Temperature, ° C.	600	600	635	635	670	670
1 min Avg. Reactor Bed Temperature, ° C.	482	472	525	525	567	570
Yield, wt %, based on H ₂ -free product						
Methane	0.92	0.40	1.00	0.56	3.20	0.99
Ethane	0.87	0.43	0.73	0.52	0.69	0.74
Ethylene	6.17	3.68	6.50	5.07	6.36	5.78
Carbon Dioxide	1.29	1.63	1.54	1.93	1.85	1.91
Propane	3.90	4.26	3.15	3.58	3.11	3.49
Propylene	12.76	11.05	13.63	12.93	14.67	14.75
i-Butane	4.56	4.99	3.85	4.75	3.77	3.53
n-Butane	2.67	1.84	2.07	1.57	1.31	1.41
t-2-Butene	3.16	2.67	3.10	2.89	2.99	3.01
1-Butene	1.75	1.63	1.79	1.79	1.90	2.01
i-Butylene	4.68	4.55	4.56	4.76	4.72	4.97
c-2-Butene	2.22	1.92	2.19	2.09	2.14	2.21
Carbon Monoxide	1.25	0.10	0.35	0.00	0.80	0.25
Gasoline	43.83	45.34	41.66	42.42	42.11	49.30
Diesel	5.75	9.14	7.55	8.37	4.73	5.16
Heavies	0.56	1.64	0.78	0.88	0.49	0.86
Coke	4.67	4.73	5.55	5.88	5.12	5.64

[0105] Overall, yield of gas products has increased and liquid products have decreased indicating higher conversions to lighter products.

	Hydro- pyrolysis 1	Pyrolysis 1	Hydro- pyrolysis 2	Pyrolysis 2	Hydro- pyrolysis 3	Pyrolysis 3
C ₁ -C ₄ Yield, wt %	45.2	39.1	44.5	42.5	47.5	45.0
Liquid Yield, wt %	50.1	56.1	50.0	51.7	47.3	49.3
Coke Yield, wt %	4.7	4.7	5.6	5.9	5.1	5.6

[0106] As can be seen, the yield of light gas olefins per unit amount of coke deposited on the catalyst is higher in the case of hydro-pyrolysis. This implies that more light gas olefins would be produced in a circulating fluid catalytic cracking type of unit. In these units, performance is compared on a constant coke yield basis. This is because the amount of coke burnt off in the regenerator is limited by the air availability in the regenerator and as a result the regenerated catalyst

returned back to the riser would have more or less coke on it which would in turn affect its activity in the riser.

[0107] The total aromatics as well as C₆-C₈ aromatics yield per unit amount of coke deposited is also higher in the case of hydro-pyrolysis. This implies in hydro-pyrolysis more aromatic products would be produced in a circulating fluid catalytic cracking type of unit.

	Hydro- pyrolysis 1	Pyrolysis 1	Hydro- pyrolysis 2	Pyrolysis 2	Hydro- pyrolysis 3	Pyrolysis 3
Total Aromatics Yield Boiling Below 240° C., wt %	32.42	31.39	32.81	31.83	35.09	32.35
C ₆ -C ₈ Aromatics Yield, wt %	23.81	23.20	24.44	22.63	26.33	22.87
Total Aromatics/Coke, wt ratio	6.9	6.6	5.9	5.4	6.9	5.7
(C ₆ -C ₈ Aromatics)/Coke, wt ratio	5.1	4.9	4.4	3.9	5.1	4.1
Light gas olefins/Coke, wt ratio	6.6	5.4	5.7	5.0	6.4	5.8

-continued

	Hydro- pyrolysis 1	Pyrolysis 1	Hydro- pyrolysis 2	Pyrolysis 2	Hydro- pyrolysis 3	Pyrolysis 3
C ₄ Olefins, wt %	11.81	10.76	11.64	11.54	11.77	12.20
C ₃ Olefins, wt %	12.76	11.05	13.63	12.93	14.67	14.75
C ₂ Olefins, wt %	6.17	3.68	6.50	5.07	6.36	5.78
Total Olefins, wt %	30.74	25.49	31.77	29.54	32.80	32.72

[0108] To summarize, more high value chemicals (i.e. light gas olefins and aromatics) are produced in hydropyrolysis as compared to pyrolysis done without use of hydrogen carrier gas.

[0109] Additional benefits include:

[0110] a. increased olefinicity of product gases;

[0111] b. increased ratio of propylene/propane as compared to ethylene to ethane and butenes/butanes;

[0112] c. lower hydrogen transfer index (i.e. ratio of C₃ and C₄ saturates/C₃ olefins) in hydropyrolysis as compared to use of nitrogen only as carrier gas; and

[0113] d. more C₄ iso-olefins are produced in as compared to 1-butene in hydropyrolysis (i.e. isomerization index is lower).

	Hydro- pyrolysis 1	Pyrolysis 1	Hydro- pyrolysis 2	Pyrolysis 2	Hydro- pyrolysis 3	Pyrolysis 3
Hydrogen Transfer Index (HTI)	0.87	1.00	0.67	0.77	0.56	0.57
Isomerization Coefficient	0.174	0.178	0.182	0.184	0.192	0.197
C ₂ Olefin/C ₂ Saturated Hydrocarbon	7.1	8.6	8.9	9.8	9.2	7.9
C ₃ Olefin/C ₃ Saturated Hydrocarbon	3.3	2.6	4.3	3.6	4.7	4.2
C ₄ Olefin/C ₄ Saturated Hydrocarbon	1.6	1.6	2.0	1.8	2.3	2.5
% of i-C ₄ /Total C ₄	23.9	28.4	21.9	26.6	22.4	20.6
% of Olefins/Total Gases	68.0	65.1	71.5	69.6	69.0	72.6
% Olefins/% Saturated Hydrocarbons	2.6	2.2	3.2	2.8	3.7	3.6

[0114] Detailed hydrocarbon analysis (DHA) of liquid products below 240° C. is in the table below:

	Hydro- pyrolysis 1	Pyrolysis 1	Hydro- pyrolysis 2	Pyrolysis 2	Hydro- pyrolysis 3	Pyrolysis 3
Paraffins, wt %	1.184	1.435	1.207	1.170	1.108	1.420
i-Paraffins, wt %	10.161	12.389	9.598	12.120	8.545	13.330
Olefins, wt %	2.944	9.159	2.555	4.858	0.976	3.900
Naphthenes, wt %	3.727	5.390	3.135	3.867	2.329	4.030
Aromatics, wt %	73.968	69.233	78.758	75.037	83.315	74.720
BTX + EX content in liquid boiling below 240° C.	54.32	51.17	58.67	53.35	62.52	52.81

Example 9

[0115] Example 9 shows a low severity pyrolysis operation. The experimental set up consisted of a stainless steel reactor pot followed by a fixed bed (tubular) reactor packed with ZSM-5 zeolite extrudates and the outlet of this tubular reactor was connected to a stainless steel condenser/receiver tank. The reactor pot was heated using heating tapes with temperature controller. An amount of 100 g of mixed plastic as per composition provided in Example 7 was charged along with ZSM-5 zeolite catalyst powder of 75 microns average particle size into the reactor and the heating was started. The reactor temperature was maintained constant at 450° C. for a period of 1 hr. The effluent from this reactor pot was continuously passed through the hot tubular reactor packed with ZSM-5 extrudates and maintained at 450° C. The product from the tubular reactor was sent to the receiver. The outgoing gas from the receiver was passed through NaOH scrubber and then diluted with N₂ and vented out through a carbon bed. Two different catalyst loadings were tested as below:

[0116] a. Experiment 1: Equivalent to 5 wt % of the feed was the catalyst charged in the tubular reactor and 5 wt % equivalent catalyst was charged in the reactor pot (i.e. 10 wt % of catalyst overall).

[0117] b. Experiment 2: Equivalent to 5 wt % of the feed was the catalyst charged in the tubular reactor and 15 wt % equivalent catalyst was charged in the reactor pot (i.e. 20 wt % catalyst overall).

[0118] FIG. 2 shows the boiling point distribution of the liquid product obtained indicated that 95 wt % of the liquid product boiled below 370° C.

[0119] The DHA analysis of the liquid product boiling below 240° C. indicated significant presence of olefins and aromatics:

Product Composition	Liquid Product boiling below 240° C. from Experiment 1, wt %	Liquid Product boiling below 240° C. from Experiment 2, wt %
Paraffins	6.5	3.1
i-Paraffins	17.6	11.7
Olefins	11.4	7.4
Naphthenes	3.8	2.5
Aromatics	47.9	66.3
Heavies	3.1	3.6
Unknown	9.8	5.5

Example 10

[0120] Example 10 demonstrates a low severity pyrolysis with PVC present in the feed. An amount of 100 g of mixed plastic feed as per the composition provided in Example 7 above was mixed with 2 wt % of ZSM-5 zeolite catalyst powder and heated in a round bottom flask fitted with a condenser. The round bottom flask was maintained at 360° C. for 1 hour. The liquid product had 60 ppmw chlorides. A similar experiment conducted with head space purging of the round bottom flask with N₂ gas provided a liquid product with no detectable chloride content. Chloride content in the liquid products was determined by fusing liquid products in NaOH followed by extraction in water and measurement of the resultant aqueous solution chloride content using ion chromatography. This example also demonstrates the possibility of head space purging in a pyrolysis unit to enhance dechlorination.

Example 11

[0121] Example 11 demonstrates a low severity pyrolysis process in a fluidized bed. An amount of 1.5 g of mixed plastic feed as per composition provided in Example 7 was mixed with 9.05 g of a catalyst mixture containing 62.5 wt % of FCC spent catalyst and 37.5 wt % of ZSM-5 Zeolite catalyst. This combined mixture was charged into the fluidized bed reactor described in Example 7. Before charging of feed and catalyst mixture the reactor was at a temperature of 450° C. The reactor temperature decreased as the feed was charged and later increased to the set point of 450° C. Data provided below also captures the temperature profile in the reactor bed as a function of time. The 1 min, 6 min, and 10 min average bed temperatures were 333° C., 369° C., and 395° C., respectively. The 1 min average represents the average reaction temperature severity when most temperature changes occur in the reactor. The 6 min average represents the temperature severity when the reactor temperature has recovered and reached the previously set value. Most of the conversion in the low severity case was expected to have been completed at the 6 min average. The data below shows that the liquid product is highly aromatic, the heavier than 370° C. boiling material is only about 2 wt %, and more than 90 wt % of the liquid product boils below 350° C.

[0122] The product yield data is shown in the table below:

	Amount, wt %
H ₂	0.03
Methane	0.00
Ethane	0.00
Ethylene	2.25
Carbon Dioxide	1.54
Propane	3.39
Propylene	6.92
i-Butane	6.48
n-Butane	1.67
t-2-Butene	1.71
1-Butene	1.04
i-Butylene	3.37
c-2-Butene	1.26
Carbon Monoxide	0.00
Gasoline	45.28
Diesel	17.64
Heavies	2.08
Coke	5.33

[0123] The boiling point distribution is in the table below:

Mass %	Boiling Point, ° C.
0.0	108.6
5.0	156.0
10.0	164.0
15.0	175.6
20.0	180.0
25.0	187.6
30.0	190.2
35.0	198.8
40.0	203.6
45.0	209.2
50.0	220.2
55.0	227.0
60.0	232.0
65.0	246.0
70.0	254.2
75.0	267.4
80.0	281.8

-continued

Mass %	Boiling Point, ° C.
85.0	300.6
90.0	332.0
95.0	371.6
99.0	431.2
100.0	454.2

[0124] The detailed analysis of the liquid product is shown in the table below:

Carbon No.	n-Paraffins, wt %	i-Paraffins, wt %	Olefins, wt %	Naphthenes, wt %	Aromatics, wt %	Total, wt %
3			0.003			0.003
4	0.007	0.012	0.041			0.06
5	0.032	0.077	0.325	0.095		0.529
6	0.173	0.566	1.025	1.009	4.757	7.53
7	0.379	1.379	1.547	2.095	19.393	24.793
8	0.398	2.443	0.198	1.518	28.466	33.023
9	0.046	1.911	0.134	0.958	11.254	14.303
10	0.019	0.916	0.02	0.156	4.448	5.559
11	0.022	2.114		0.029	1.621	3.786
12	0.029	0.199	0.199	0.057	3.884	4.169
13		0.078	0.111			0.189
Unknown						2.842
Heavies						3.214
Total, wt %	1.105	9.695	3.404	5.917	78.823	93.944
Total, wt % on Aromatics- Free Basis	5.49	48.18	16.92	29.41		100

[0130] At ambient temperature, the hydroprocessing reactor (having previously been loaded with the hydroprocessing catalyst) was purged with hydrogen for 30 to 60 minutes at a set operating pressure (e.g., 40 to 60 barg). The set operating pressure was maintained by venting the reactor when the pressure of the reactor during hydrogen purging increased above the set operating pressure (e.g., due to a hydrogen source pressure greater than the set operating pressure).

[0131] After purging the hydroprocessing reactor for 30 to 60 minutes at ambient temperature, the hydrogen purge was stopped.

Example 12

[0125] Example 12 demonstrates how a steam cracker is used in combination with pyrolysis and hydroprocessing unit. Gases (C₁-C₄) from a pyrolysis unit and hydroprocessing facility are fed to gas crackers. Liquids from the hydroprocessing facility are fed to liquid steam crackers.

[0126] Gas steam cracking of a feed consisting of 16.75 wt % ethane, 34.62 wt % propane, 27.62 wt % isobutene and 21 wt % butane, carried out at a steam cracker coil outlet temperature of 840° C., a steam/hydrocarbon ratio of 0.35, and a coil outlet pressure of 1.7 bar, resulted in a product having 0.48 wt % acetylene, 34.1 wt % ethylene, 12.21 wt % propylene, and 2.41 wt % butadiene, among other products.

[0127] Steam cracking a naphtha feed (boiling cut from initial boiling point to 220° C.) having 20.3 wt % paraffin, 27.9 wt % i-paraffins, 14.5 wt % aromatics, and 36.9 wt % naphthenes at a coil outlet temperature of 865° C., a coil outlet pressure of 1.7 bar, and a steam to oil ratio of 0.5 resulted in a product having 25.86 wt % ethylene, 12.14 wt % propylene, and 4.98 wt % butadiene.

[0128] Steam cracking of gas oils (>220° C. boiling point to 380° C.) resulted in a product having 24 wt % ethylene, 14.45 wt % propylene, 4.7 wt % butadiene, and 4.5 wt % butenes.

Example 13

[0129] Example 13 demonstrates a process for sulphiding a hydroprocessing catalyst. The particular steps of the process are shown in FIG. 3. The time of 0 hours (zero time) in FIG. 3 corresponds to a time after the hydroprocessing catalyst is introduced into the hydroprocessing reactor.

[0132] Still at the ambient temperature, the sulphiding feed was then introduced into the reactor using a high pressure pump against the set reactor pressure at a weight hourly space velocity (WHSV) of 3 hr⁻¹ (on bone-dry catalyst basis). The sulphiding feed (e.g., for use in spiking stream 14 of FIG. 1) was prepared by mixing n-hexadecane with dimethyl disulphide in appropriate quantity to give 3 wt % sulphur based on total weight of the sulphiding feed. For the sulphiding feed, as per catalyst sulphiding protocol followed, cracked feedstock cannot be used. Hence, n-hexadecane is used. In place of n-hexadecane, straight-run naphtha, diesel, or vacuum gas oils can also be used.

[0133] FIG. 3 indicates the hydroprocessing catalyst was soaked with a sulphiding feed without a flow of hydrogen in the reactor and at ambient temperature for a period of 3 hours (ending at time 3.5 hours after zero time in FIG. 3). Catalyst soaking provides for complete wetting of the hydroprocessing catalyst; however, soaking is optional. Liquid was drained from the bottom of a downstream gas liquid separator.

[0134] After introducing the sulphiding feed to the reactor, the hydroprocessing reactor bed temperature was raised to 250° C. at a rate of 30° C. per hour with a flow of H₂ at a ratio of 200 NL H₂/L liquid feed. As shown in FIG. 3, the temperature was increased from a time of 3.5 hours to a time of 10.8 hours after zero time.

[0135] The hydroprocessing reactor bed temperature was then held at 250° C. for a period of 8 hours. As shown in FIG. 3, the temperature was held from a time of 10.8 hours to a time of 18.8 hours after zero time.

[0136] After holding the bed temperature, the bed temperature was further increased to 320° C. to 350° C. at a rate of 20° C. per hour without any temperature overshoot at the final

temperature. As shown in FIG. 3, the temperature was increased from a time of 18.8 hours to a time of 22.3 hours after zero time.

[0137] The hydroprocessing reactor bed temperature was then maintained at 320° C. to 350° C. for a period of 8 hours. As shown in FIG. 3, the temperature was maintained at 320° C. to 350° C. from a time of 22.3 hours to a time of 30.0 hours after zero time.

[0138] During the step of maintaining the temperature at 320° C. to 350° C. for 8 hours, after 5 hours of maintaining the temperature at 320° C. to 350° C., gas sampling began, and a first gas sample was obtained from the reactor effluent. A second gas sample was obtained close to 8 hours while the bed temperature is maintained at 320° C. to 350° C. The first and second gas samples were analyzed in a refinery gas analyzer (RGA) gas chromatograph and constancy of H₂S concentration in reactor effluent gases in the first and second samples signified further uptake of sulphur on the catalyst did not take place. This marked the completion of the catalyst sulphiding process. If the first and second samples had not exhibited constancy in H₂S concentration, additional samples would have been taken and the temperature maintained until two successive samples exhibited constancy in H₂S concentration.

[0139] The present disclosure is further illustrated by the following embodiments, which are not to be construed in any way as imposing limitations upon the scope thereof. On the contrary, it is to be clearly understood that resort can be had to various other aspects, embodiments, modifications, and equivalents thereof which, after reading the description herein, can be suggest to one of ordinary skill in the art without departing from the spirit of the present invention or the scope of the appended claims.

Additional Disclosure

[0140] The following are enumerated embodiments which are provided as non-limiting examples:

[0141] A first embodiment, which is a process for converting waste plastics to a high value product comprising:

[0142] converting the waste plastics to a hydrocarbon stream in a liquid phase;

[0143] contacting the hydrocarbon stream with a hydroprocessing catalyst in the presence of hydrogen to yield a hydrocarbon product comprising C₁ to C₄ gases and C₅+ liquid hydrocarbons;

[0144] recovering the C₅+ liquid hydrocarbons in a treated hydrocarbon stream from the hydrocarbon product; and

[0145] feeding the treated hydrocarbon stream or a blended hydrocarbon stream comprising the treated hydrocarbon stream to a steam cracker to yield the high value product,

[0146] wherein the treated hydrocarbon stream or blended hydrocarbon stream meets steam cracker feed requirements for chloride content, olefin content, and boiling end point.

[0147] A second embodiment, which is the process of the first embodiment, wherein the hydrocarbon stream comprises one or more chloride compounds in a concentration of 5 ppm or more based on a total weight of the hydrocarbon stream, wherein the treated hydrocarbon stream comprises the one or more chloride compounds in a concentration of less than 5 ppm based on a total weight of the treated hydrocarbon stream.

[0148] A third embodiment, which is the process of the second embodiment, wherein the treated hydrocarbon stream

comprises the one or more chloride compounds in a concentration of less than 1 ppm based on the total weight of the treated hydrocarbon stream.

[0149] A fourth embodiment, which is the process of any one of the second through the third embodiments, wherein the hydrocarbon stream comprises the one or more chloride compounds in a concentration of greater than 200 ppmw based on a total weight of the hydrocarbon stream.

[0150] A fifth embodiment, which is the process of any one of the first through the fourth embodiments, wherein the hydrocarbon stream comprises one or more olefins, wherein the treated hydrocarbon stream comprises the one or more olefins in a concentration of less than 1 wt. % based on the total weight of the treated hydrocarbon stream.

[0151] A sixth embodiment, which is the process of the fifth embodiment, wherein the one or more olefins are present in the hydrocarbon stream in a concentration of 20 wt % or more based on the total weight of the hydrocarbon stream.

[0152] A seventh embodiment, which is the process of any one of the fifth through the sixth embodiments, wherein the concentration of the one or more olefins in the treated hydrocarbon stream is less than the concentration of the one or more olefins in the hydrocarbon stream due to hydrogenation of at least a portion of the one or more olefins from the hydrocarbon stream during the step of contacting.

[0153] An eighth embodiment, which is the process of any one of the fifth through the seventh embodiments, wherein the concentration of the one or more olefins in the treated hydrocarbon stream is less than the concentration of the one or more olefins in the hydrocarbon stream due to hydrogenation and hydrocracking of at least a portion of the one or more olefins from the hydrocarbon stream during the step of contacting.

[0154] A ninth embodiment, which is the process of any one of the first through the eighth embodiments, wherein the hydrocarbon stream comprises heavy hydrocarbon molecules.

[0155] A tenth embodiment, which is the process of the ninth embodiment, further comprising:

[0156] hydrocracking at least a portion of the heavy hydrocarbon molecules during the step of contacting.

[0157] An eleventh embodiment, which is the process of any one of the ninth to the tenth embodiments, wherein the treated hydrocarbon stream comprises at least a portion of the heavy hydrocarbon molecules, wherein a concentration of the heavy hydrocarbon molecules in the treated hydrocarbon stream is less than a concentration of the heavy hydrocarbon molecules in the hydrocarbon stream due to hydrocracking of at least a portion of the heavy hydrocarbon molecules from the hydrocarbon stream during the step of contacting.

[0158] A twelfth embodiment, which is the process of any one of the ninth through the eleventh embodiments, wherein the treated hydrocarbon stream comprises none of the heavy molecules due to hydrocracking of the heavy hydrocarbon molecules from the hydrocarbon stream during the step of contacting.

[0159] A thirteenth embodiment, which is the process of any one of the ninth through the twelfth embodiments, wherein the hydrocarbon stream further comprises one or more olefins, wherein at least a portion of the one or more olefins comprises at least a portion of the heavy molecules.

[0160] A fourteenth embodiment, which is the process of any one of the ninth through the thirteenth embodiments, wherein the hydrocarbon stream further comprises paraffins,

wherein at least a portion of the paraffins comprises at least a portion of the heavy molecules.

[0161] A fifteenth embodiment, which is the process of any one of the first through the fourth, the ninth through the twelfth, and the fourteenth embodiments, wherein the hydrocarbon stream comprises no olefins.

[0162] A sixteenth embodiment, which is the process of any one of the ninth through the fifteenth embodiments, wherein none of the heavy molecules are olefins.

[0163] A seventeenth embodiment, which is the process of any one of first through sixteenth embodiments, wherein the treated hydrocarbon stream has a boiling end point of 370° C.

[0164] An eighteenth embodiment, which is the process of any one of the ninth through the seventeenth embodiments, wherein the at least a portion of the heavy hydrocarbon molecules which are hydrocracked during the step of contacting is greater than 5 wt % based on the weight of heavy hydrocarbon molecules in the hydrocarbon stream.

[0165] A nineteenth embodiment, which is the process of any one of the ninth through the eighteenth embodiments, wherein a concentration of the heavy hydrocarbon molecules in the hydrocarbon stream is 10 wt % to 90 wt % based on the total weight of the hydrocarbon stream.

[0166] A twentieth embodiment, which is the process of any one of the of the ninth through the nineteenth embodiments, wherein the heavy hydrocarbon molecules comprise C₁₆ and larger hydrocarbons.

[0167] A twenty-first embodiment, which is the process of the twentieth embodiment, wherein the C₁₆ and larger hydrocarbons comprise paraffins, i-paraffins, olefins, naphthenes, aromatic compounds, or combinations thereof.

[0168] A twenty-second embodiment, which is the process of any one of the first through the twenty-first embodiments, wherein the hydrocarbon stream is one or more of a plastic pyrolysis oil and a tire pyrolysis oil.

[0169] A twenty-third embodiment, which is the process of any one of the first through the twenty-second embodiments, further comprising:

[0170] before the step of contacting, contacting a catalyst activating stream comprising one or more sulphides with the hydroprocessing catalyst.

[0171] A twenty-fourth embodiment, which is the process of the twenty-third embodiment, wherein the one or more sulphides of the catalyst activating stream are present in an amount such that a sulphur content of the catalyst activating stream is about 0.5 wt % to about 5 wt % based on the total weight of the catalyst activating stream.

[0172] A twenty-fifth embodiment, which is the process of any one of the first through the twenty-fourth embodiments, wherein the hydrocarbon stream further comprises one or more sulphides.

[0173] A twenty-sixth embodiment, which is the process of the twenty-fifth embodiment, wherein the one or more sulphides of the hydrocarbon stream are present in an amount such that a sulphur content of the hydrocarbon stream is about 0.5 wt % to about 5 wt % based on the total weight of the hydrocarbon stream.

[0174] A twenty-seventh embodiment, which is the process of any one of the first through the twenty-sixth embodiments, wherein the step of contacting is performed at a temperature of 100° C. to 450° C.

[0175] A twenty-eighth embodiment, which is the process of any one of the first through the twenty-seventh embodi-

ments, wherein the step of contacting is performed at a temperature of 100° C. to 350° C.

[0176] A twenty-ninth embodiment, which is the process of any one of the first through the twenty-eighth embodiments, wherein the step of contacting is performed at a temperature of 260° C. to 350° C.

[0177] A thirtieth embodiment, which is the process of any one of the first through the twenty-ninth embodiments, wherein the step of contacting is performed at a weight hourly space velocity of 0.1 to 10 hr⁻¹.

[0178] A thirty-first embodiment, which is the process of any one of the first through the thirtieth embodiments, wherein the step of contacting is performed at a hydrogen to hydrocarbon ratio of 10 to 3,000 NL/L.

[0179] A thirty-second embodiment, which is the process of any one of the first through the thirty-first embodiments, wherein the step of contacting is performed at a pressure of 1 to 200 barg.

[0180] A thirty-third embodiment, which is the process of any one of the first through the thirty-second embodiments, wherein the treated hydrocarbon stream comprises the one or more chloride compounds in a concentration of less than 3 ppm based on a total weight of the treated hydrocarbon stream, and wherein the treated hydrocarbon stream is fed directly to the stream cracker.

[0181] A thirty-fourth embodiment, which is the process of any one of the first through the thirty-third embodiments, further comprising:

[0182] blending the treated hydrocarbon stream with a non-chlorinated hydrocarbon stream to yield the blended hydrocarbon stream comprising the one or more chloride compounds in a concentration of less than 3 ppm based on a total weight of the blended hydrocarbon stream, wherein the blended hydrocarbon stream is fed to the steam cracker.

[0183] A thirty-fifth embodiment, which is the process of any one of the first through the thirty-fourth embodiments, wherein the hydroprocessing catalyst comprises cobalt and molybdenum on an alumina support, nickel and molybdenum on an alumina support, tungsten and molybdenum on an alumina support, or nickel and molybdenum sulphides.

[0184] A thirty-sixth embodiment, which is the process of the thirty-fifth embodiment, wherein contacting the hydrocarbon stream with the hydroprocessing catalyst comprises:

[0185] contacting one or more sulphides contained in or added to the hydrocarbon stream with the hydroprocessing catalyst.

[0186] A thirty-seventh embodiment, which is the process of the thirty-sixth embodiment, wherein the one or more sulphides are contained in or added to the hydrocarbon stream in an amount such that a sulphur content of the hydrocarbon stream is about 0.5 wt % to about 5 wt % based on the total weight of the hydrocarbon stream.

[0187] A thirty-eighth embodiment, which is the process of the first through the thirty-seventh embodiments, wherein the high value products are ethylene, propylene, butene, butadiene, aromatic compounds, or combinations thereof.

[0188] A thirty-ninth embodiment, which is the process of any one of the first through the thirty-eighth embodiments, wherein the step of converting comprises:

[0189] subjecting the waste plastics to a pyrolysis process to produce one or more plastic pyrolysis oil in the hydrocarbon stream.

[0190] A fortieth embodiment, which is the process of the thirty-ninth embodiment, wherein the pyrolysis process occurs at a temperature of 250° C. to 450° C.

[0191] A forty-first embodiment, which is the process of any one of the thirty-ninth through the fortieth embodiments, wherein the pyrolysis process occurs at a temperature of 450° C. to 750° C.

[0192] A forty-second embodiment, which is the process of any one of the thirty-ninth through the forty-first embodiments, wherein the step of subjecting the waste plastics to a pyrolysis process utilizes a catalyst comprising zeolite, sand, or both.

[0193] A forty-third embodiment, which is the process of any one of the thirty-ninth through the forty-second embodiments, wherein the step of subjecting comprises a first stage and a second stage fluidly connected downstream of the first stage, wherein the first stage utilizes thermal cracking of the waste plastics and the second stage utilizes catalytic cracking of the waste plastics to yield the hydrocarbon stream flowing from the second stage.

[0194] A forty-fourth embodiment, which is the process of any one of the thirty-ninth through the forty-third embodiments, wherein the step of subjecting comprises a first stage and a second stage fluidly connected downstream of the first stage, wherein the first stage utilizes catalytic cracking of the waste plastics and the second stage utilizes thermal cracking of the waste plastics to yield the hydrocarbon stream flowing from the second stage.

[0195] A forty-fifth embodiment, which is the process of any one of the first through the forty-fourth embodiments, wherein recovering a treated hydrocarbon stream from the hydrocarbon product comprises:

[0196] separating a treated product from a sulphur and chlorine-containing gas in a separator; and

[0197] flowing the treated product in the treated hydrocarbon stream from the separator.

[0198] A forty-sixth embodiment, which is the process of any one of the first through the forty-fifth embodiments, wherein no hydrogen halides and no halogenated organic compounds are recycled to the hydroprocessing reactor.

[0199] A forty-seventh embodiment, which is the process of any one of the first through the forty-sixth embodiments, wherein the step of contacting is performed without use of chlorine sorbents.

[0200] A forty-eighth embodiment, which is the process of any one of the first through the forty-seventh embodiments, wherein the step of contacting is performed without the presence of Na_2CO_3 in an effective amount to function as a dechlorinating agent.

[0201] A forty-ninth embodiment, which is the process of any one of the first through the forty-eighth embodiments, wherein the hydroprocessing reactor is configured to operate in the slurry phase.

[0202] A fiftieth embodiment, which is the process of any one of the first through the forty-ninth embodiments, wherein the step of contacting includes simultaneous i) dechlorination of the hydrocarbon stream such that the treated hydrocarbon stream comprises one or more chloride compounds in a concentration less than 1 ppm based on the total weight of the treated hydrocarbon stream, ii) hydrogenation of the hydrocarbon stream such that the treated hydrocarbon stream comprises one or more olefins in a concentration less than 1 wt %

based on the total weight of the treated hydrocarbon stream, and iii) reduction of heavy hydrocarbon molecules of the hydrocarbon stream.

[0203] A fifty-first embodiment, which is the process of any one of the first through the fiftieth embodiments, wherein 2 wt % or less of the hydrocarbon stream in a liquid phase boils above 370° C.

[0204] A fifty-second embodiment, which is the process of any one of the first through the fifty-first embodiments, wherein the step of converting the waste plastics to a hydrocarbon stream in a liquid phase utilizes hydrogen.

[0205] A fifty-third embodiment, which is the process of any one of the first through the fifty-second embodiments, further comprising:

[0206] converting the waste plastics to C_1 to C_4 pyrolysis gases;

[0207] wherein the C_1 to C_4 pyrolysis gases and the C_1 to C_4 gases yielded in the step of contacting are fed to the steam cracker.

[0208] A fifty-fourth embodiment, which is the process of the fifty-third embodiment, wherein the C_1 to C_4 pyrolysis gases are treated to remove sulphur and chlorine-containing gases before the C_1 to C_4 pyrolysis gases are fed to the steam cracker.

[0209] A fifty-fifth embodiment, which is the process of any one of the fifty-third through the fifty-fourth embodiments, wherein the step of converting the waste plastics to the hydrocarbon stream and the step of converting the waste plastics to C_1 to C_4 pyrolysis gases occurs simultaneously via pyrolysis of the waste plastics.

[0210] A fifty-sixth embodiment, which is the process of any one of the first through the fifty-fifth embodiments, wherein converting the waste plastics to a hydrocarbon stream in a liquid phase is performed in the presence of a head space purge gas fed to a pyrolysis unit, wherein the head space purge gas comprises hydrogen, nitrogen, steam, product gases, or combinations thereof.

What is claimed is:

1. A process for converting waste plastics to a high value product comprising:

converting the waste plastics to a hydrocarbon stream in a liquid phase;

contacting the hydrocarbon stream with a hydroprocessing catalyst in the presence of hydrogen to yield a hydrocarbon product comprising C_1 to C_4 gases and C_5 + liquid hydrocarbons;

recovering the C_5 + liquid hydrocarbons in a treated hydrocarbon stream from the hydrocarbon product; and

feeding the treated hydrocarbon stream or a blended hydrocarbon stream comprising the treated hydrocarbon stream to a steam cracker to yield the high value product, wherein the treated hydrocarbon stream or blended hydrocarbon stream meets steam cracker feed requirements for chloride content, olefin content, and boiling end point.

2. The process of claim 1, wherein the hydrocarbon stream comprises one or more chloride compounds in a concentration of 5 ppm or more based on a total weight of the hydrocarbon stream, wherein the treated hydrocarbon stream comprises the one or more chloride compounds in a concentration of less than 5 ppm based on a total weight of the treated hydrocarbon stream.

3. The process of claim 1, wherein the hydrocarbon stream comprises one or more olefins, wherein the treated hydrocar-

bon stream comprises the one or more olefins in a concentration of less than 1 wt. % based on the total weight of the treated hydrocarbon stream, and wherein the one or more olefins are present in the hydrocarbon stream in a concentration of 20 wt % or more based on the total weight of the hydrocarbon stream.

4. The process of claim 1, wherein the hydrocarbon stream comprises heavy hydrocarbon molecules, and further comprising:

hydrocracking at least a portion of the heavy hydrocarbon molecules during the step of contacting.

5. The process of claim 1, further comprising:

before the step of contacting, contacting a catalyst activating stream comprising one or more sulphides with the hydroprocessing catalyst, and wherein the one or more sulphides of the catalyst activating stream are present in an amount such that a sulphur content of the catalyst activating stream is about 0.5 wt % to about 5 wt % based on the total weight of the catalyst activating stream.

6. The process of claim 1, wherein the step of contacting is performed at a weight hourly space velocity of 0.1 to 10 hr⁻¹, at a hydrogen to hydrocarbon ratio of 10 to 3,000 NL/L, and at a pressure of 1 to 200 barg.

7. The process of claim 1, wherein the treated hydrocarbon stream comprises the one or more chloride compounds in a concentration of less than 3 ppm based on a total weight of the treated hydrocarbon stream, and wherein the treated hydrocarbon stream is fed directly to the steam cracker.

8. The process of claim 1, further comprising:

blending the treated hydrocarbon stream with a non-chlorinated hydrocarbon stream to yield the blended hydrocarbon stream comprising the one or more chloride compounds in a concentration of less than 3 ppm based on a total weight of the blended hydrocarbon stream, wherein the blended hydrocarbon stream is fed to the steam cracker.

9. The process of claim 1, wherein the hydroprocessing catalyst comprises cobalt and molybdenum on an alumina support, nickel and molybdenum on an alumina support, tungsten and molybdenum on an alumina support, or nickel and molybdenum sulphides.

10. The process of claim 9, wherein contacting the hydrocarbon stream with the hydroprocessing catalyst comprises: contacting one or more sulphides contained in or added to the hydrocarbon stream with the hydroprocessing catalyst.

11. The process of claim 10, wherein the one or more sulphides are contained in or added to the hydrocarbon stream in an amount such that a sulphur content of the hydrocarbon stream is about 0.5 wt % to about 5 wt % based on the total weight of the hydrocarbon stream.

12. The process of claim 1, wherein the high value products are ethylene, propylene, butene, butadiene, aromatic compounds, or combinations thereof.

13. The process of claim 1, wherein the step of converting comprises:

subjecting the waste plastics to a pyrolysis process to produce one or more plastic pyrolysis oil in the hydrocarbon stream.

14. The process of claim 13, wherein the step of subjecting comprises a first stage and a second stage fluidly connected downstream of the first stage, wherein the first stage utilizes thermal cracking of the waste plastics and the second stage utilizes catalytic cracking of the waste plastics to yield the hydrocarbon stream flowing from the second stage.

15. The process of claim 13, wherein the step of subjecting comprises a first stage and a second stage fluidly connected downstream of the first stage, wherein the first stage utilizes catalytic cracking of the waste plastics and the second stage utilizes thermal cracking of the waste plastics to yield the hydrocarbon stream flowing from the second stage.

16. The process of claim 1, wherein recovering a treated hydrocarbon stream from the hydrocarbon product comprises:

separating a treated product from a sulphur and chlorine-containing gas in a separator; and

flowing the treated product in the treated hydrocarbon stream from the separator.

17. The process of claim 1, wherein the step of contacting includes simultaneous i) dechlorination of the hydrocarbon stream such that the treated hydrocarbon stream comprises one or more chloride compounds in a concentration less than 1 ppm based on the total weight of the treated hydrocarbon stream, ii) hydrogenation of the hydrocarbon stream such that the treated hydrocarbon stream comprises one or more olefins in a concentration less than 1 wt % based on the total weight of the treated hydrocarbon stream, and iii) reduction of heavy hydrocarbon molecules of the hydrocarbon stream.

18. The process of claim 1, further comprising:

converting the waste plastics to C₁ to C₄ pyrolysis gases; wherein the C₁ to C₄ pyrolysis gases and the C₁ to C₄ gases yielded in the step of contacting are fed to the steam cracker.

19. The process of claim 18, wherein the C₁ to C₄ pyrolysis gases are treated to remove sulphur and chlorine-containing gases before the C₁ to C₄ pyrolysis gases are fed to the steam cracker.

20. The process of claim 1, wherein converting the waste plastics to a hydrocarbon stream in a liquid phase is performed in the presence of a head space purge gas fed to a pyrolysis unit, wherein the head space purge gas comprises hydrogen, nitrogen, steam, product gases, or combinations thereof.

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