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### Processes and Systems for Steam Cracking Hydrocarbon Feeds

#### Abstract

Processes for steam cracking hydrocarbons. The process can include introducing a hydrocarbon that can include ethane, propane, or a mixture thereof into radiant coils under steam cracking conditions that produce a steam cracker effluent and deposit coke on an inner surface thereof. An ethane conversion can be  $\leq 75\%$  or a propane conversion can be  $\leq 93\%$ . Introduction of the hydrocarbon into at least one of the radiant coils can be periodically stopped. A decoking feed can be introduced into the at least one of the radiant coils under decoking process conditions that can include: (i) a decoking effluent that can have a coil outlet temperature of  $>900^{\circ}\text{C}$ . (ii) introducing the decoking feed at a mass flux rate at the quench exchanger inlet of  $>39\text{ kg m.sup.-2 second.sup.-1}$ , and/or (iii) introducing the decoking feed while maintaining introduction of the first hydrocarbon feed into one or more of the radiant coils in the plurality of radiant coils.

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## **Background/Summary**

CROSS-REFERENCE TO RELATED APPLICATION [0001] This application claims priority to and the benefit of U.S. Provisional Application No. 63/286,377 having a filing date of Dec. 6, 2021, the disclosure of which is incorporated herein by reference in its entirety

### **FIELD**

[0002] Embodiments disclosed herein generally relate to processes for steam cracking hydrocarbons for the production of olefins, particularly low molecular weight olefins such as ethylene and propylene. More particularly, such embodiments relate to processes for removing coke deposits that form within radiant coils of a steam cracker and/or within one or more quench exchanger inlets during steam cracking of the hydrocarbons under a high conversion of ethane and/or propane to one or more other compounds.

### **BACKGROUND**

[0003] Steam cracking is a primary means used to generate ethylene and propylene and other products from a variety of feedstocks. Modern plants employ optimization models and controls to optimize profit. Neither ethane nor propane can be converted entirely to products in a steam cracking furnace due to the excessive formation of coke. Despite capital cost, utility cost, energy, and environmental benefits for increasing conversion, steam cracking furnace operators limit ethane conversion to 70% and limit propane conversion to 90%. Unconverted ethane and/or propane in the steam cracker effluent is separated therefrom, compressed, refrigerated, and recycled back to the steam cracker furnace for cracking to extinction. Coking constraints result in reduced run-lengths between decokes or mechanical cleanings, causing operational challenges.

[0004] At increased conversion, not only would the rate of coke formation increase, but also coking severity changes too. Higher temperatures would result in more dehydrogenation and hardening of coke, resulting in coke that is more graphitic and less reactive to combustion. These factors would make such coke more resistant to removal via conventional decoking processes. If decoking does not remove coke, operators would need to use more severe alternative methods of decoking, including mechanical cleaning during costly and potentially hazardous furnace outages to remove coke from radiant coils and/or quench exchangers. The cost and effort associated with these alternative methods are the primary reasons operators are discouraged from pursuing increased conversion of ethane and/or propane to one or more other compounds.

[0005] There is a need, therefore, for improved processes for steam cracking ethane to one or more other compounds at a conversion of  $\geq 75\%$  and/or steam cracking propane to one or more other compounds at a conversion of  $\geq 93\%$  and for removing coke formed within radiant coils of the steam cracker and/or within one or more quench exchanger inlets. This disclosure satisfies this and other needs.

### **SUMMARY**

[0006] Processes and systems for steam cracking hydrocarbons are provided. In some embodiments, the process for steam cracking hydrocarbons can include (A) providing an olefins production plant comprising a steam cracking furnace and an olefins product recovery section. A first hydrocarbon feed comprising at least one of ethane and propane can be introduced into a

plurality of radiant coils disposed within the steam cracking furnace under first steam cracking conditions that produce a first steam cracker effluent and deposit coke on an inner surface of the radiant coils. A conversion of ethane, if present at a molar concentration in the first hydrocarbon feed equal to or greater than that of propane, to one or more other compounds is  $\geq 75\%$ . Or a conversion of propane, if present at a molar concentration in the first hydrocarbon feed higher than that of ethane feed, to one or more other compounds is  $\geq 93\%$ . The introduction of the first hydrocarbon feed into at least one of the radiant coils in the plurality of radiant coils can be periodically stopped. A decoking feed comprising steam and optionally air can be introduced into the at least one of the radiant coils under decoking process conditions. The decoking process conditions can comprise at least one of: (i) introducing the decoking feed into the at least one of the radiant coils to produce a decoking effluent having a coil outlet temperature of  $>900^\circ\text{C}$ .; (ii) introducing the decoking feed into the at least one of the radiant coils or into one or more quench exchanger inlets in fluid communication with the at least one of the radiant coils at a mass flux rate at the quench exchanger inlet of  $>39\text{ kg.Math.m.sup.-2.Math.second.sup.-1}$ ; and (iii) introducing the decoking feed into the at least one of the radiant coils while maintaining introduction of the first hydrocarbon feed into one or more of the radiant coils in the plurality of radiant coils.

[0007] In other embodiments, process for steam cracking hydrocarbons may comprise introducing a hydrocarbon feed comprising ethane, propane, or a mixture thereof into a plurality of radiant coils disposed within a steam cracking furnace under steam cracking conditions that produce a steam cracker effluent and deposit coke on an inner surface of the radiant coils. A conversion of at least one of ethane, if present at a molar concentration in the first hydrocarbon feed equal to or greater than that of propane (based on the total moles of molecules in the first hydrocarbon feed), to one or more other compounds is  $\geq 75\%$ . Or a conversion of propane, if present at a molar concentration in the first hydrocarbon feed higher than that of ethane feed (based on the total moles of molecules in the first hydrocarbon feed), to one or more other compounds is  $\geq 93\%$ . An inner surface of the radiant coils in the plurality of radiant coils may comprise a material that is non-catalytic to coke generation.

[0008] In other embodiments, process for steam cracking hydrocarbons may comprise (1) providing an olefins production plant comprising a steam cracking furnace and an olefins product recovery section. In a cracking interval, a first hydrocarbon feed comprising at least one of ethane and propane is introduced into a plurality of radiant coils disposed within the steam cracking furnace under first steam cracking conditions that produce a first steam cracker effluent and deposit coke on an inner surface of the radiant coils. A conversion of ethane, if present at a molar concentration in the first hydrocarbon feed equal to or greater than that of propane, to one or more other compounds is  $\geq 75\%$ . Or a conversion of propane, if present at a molar concentration in the first hydrocarbon feed higher than that of ethane feed, to one or more other compounds is  $\geq 93\%$ . Online decoking in an online decoking interval of at least one of the radiant coils can be optionally conducted by introducing a decoking steam there into. Periodically introduction of the first hydrocarbon feed into at least one of the radiant coils in the plurality of radiant coils maybe stopped. A reference process comprising the following may be provided: (a) in a reference cracking interval, introducing a reference steam cracker feed (preferably the same as the first hydrocarbon feed) into the plurality of radiant coils under reference steam cracking conditions that produce a reference steam cracker effluent and deposit coke on the inner surface of the radiant coils, having a reference conversion of ethane, if present at higher molar concentration in the reference steam cracker feed than propane, to one or more other compounds of  $\geq 75\%$ , and a reference conversion of propane, if present, to one or more other compounds of  $\geq 93\%$ ; (b) periodically stopping introduction of a reference steam cracker feed into at least one of the radiant coils in the plurality of radiant coils; and (c) in a reference offline decoking interval, introducing the decoking feed into the at least one of the radiant coils under reference decoking conditions. A decoking feed comprising steam and optionally air is introduced into the at least one of the radiant coils under decoking

process conditions such that [0009]  $-2 \text{ millimeter ("mm")} \leq AA \leq 2 \text{ mm}$ , where

[00001]

$AA = R1(\text{ref}) * D1(\text{ref}) + R(\text{ref}) * \text{delta}(D1) + \text{delta}(R1) * (D1(\text{ref}) + \text{delta}(D1)) - P1 - (P2 - P2(\text{ref}))$ ;

[0010]  $\text{delta}(R1) = R - R(\text{ref})$ , where R is average coke deposition rate in the radiant coils in the process during the cracking interval, in millimeter.Math.day.sup.-1 (mm.Math.day.sup.-1), and R(ref) is average coke deposition rate in the radiant coils in the reference process during the reference cracking interval, in mm.Math.day.sup.-1; [0011] D1(ref) is the duration of the reference cracking interval, in days; [0012]  $\text{Delta}(D1) = D1 - D1(\text{ref})$ , where D1 is duration of the cracking interval, in days; [0013] P1 is coke removed during the online decoking interval, if any, in mm; [0014] P2 is coke removed during the offline decoking interval, in mm; and [0015] P2(ref) is coke removed during the reference offline decoking interval, in mm.

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## Description

### BRIEF DESCRIPTION OF THE DRAWING

[0016] So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0017] The FIGURE depicts a schematic of an illustrative steam cracking furnace in operation to convert first and second hydrocarbon feeds within radiant coils disposed within a firebox in the stream cracking furnace, according to one or more embodiments described.

### DETAILED DESCRIPTION

[0018] It is to be understood that the following disclosure describes several exemplary embodiments for implementing different features, structures, and/or functions of the invention. Exemplary embodiments of components, arrangements, and configurations are described below to simplify the present disclosure; however, these exemplary embodiments are provided merely as examples and are not intended to limit the scope of the invention. Additionally, the present disclosure may repeat reference numerals and/or letters in the various exemplary embodiments and across the FIGURE provided herein. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various exemplary embodiments and/or configurations discussed in the FIGURE. Moreover, the exemplary embodiments presented below can be combined in any combination of ways, i.e., any element from one exemplary embodiment can be used in any other exemplary embodiment, without departing from the scope of the disclosure.

[0019] The indefinite article “a” or “an”, as used herein, means “at least one” unless specified to the contrary or the context clearly indicates otherwise. Thus, embodiments using “a separator” include embodiments where one or two or more separators are used, unless specified to the contrary or the context clearly indicates that only one separator is used. Likewise, embodiments using “a separation stage” include embodiments where one or two or more separation stages are used, unless specified to the contrary.

[0020] Certain embodiments and features have been described using a set of numerical upper limits and a set of numerical lower limits. It should be appreciated that ranges including the combination of any two values, e.g., the combination of any lower value with any upper value. the combination of any two lower values, and/or the combination of any two upper values are contemplated unless otherwise indicated. Certain lower limits, upper limits and ranges appear in one or more claims below. All numerical values are “about” or “approximately” the indicated value, and take into

account experimental error and variations that would be expected by a person having ordinary skill in the art.

[0021] As used herein, the term “hydrocarbon” means a class of compounds containing hydrogen bound to carbon. The term “C.sub.n” hydrocarbon means hydrocarbon having n carbon atom(s) per molecule, where n is a positive integer. The term “C.sub.n+” hydrocarbon means hydrocarbon having at least n carbon atom(s) per molecule, where n is a positive integer. The term “C.sub.n–” hydrocarbon means hydrocarbon having no more than n number of carbon atom(s) per molecule, where n is a positive integer. “Hydrocarbon” encompasses (i) saturated hydrocarbon, (ii) unsaturated hydrocarbon, and (iii) mixtures of hydrocarbons, including mixtures of hydrocarbon compounds (saturated and/or unsaturated), including mixtures of hydrocarbon compounds having different values of n.

[0022] As used herein, the term “hydrocarbon feed” means any feed that includes hydrocarbon and is suitable for producing C.sub.2+ unsaturated hydrocarbons, e.g., ethylene and/or propylene, by pyrolysis, such as by steam cracking. Typical hydrocarbon feeds include  $\geq 10\%$  hydrocarbon (weight basis, based on the weight of the first hydrocarbon feed), e.g.,  $\geq 50\%$ , such as  $\geq 90\%$ , or  $\geq 95\%$ , or  $\geq 99\%$ .

[0023] “Consisting essentially of” a given material means comprising the given material at a concentration of  $\geq 50$  wt %, preferably  $\geq 60$  wt %, preferably  $\geq 80$  wt %, preferably 90 wt %, preferably  $\geq 95$  wt %, based on the total weight of an identified mixture comprising the given material in question. Thus, a hydrocarbon feed consisting essentially of C5+ hydrocarbons is a hydrocarbon feed comprising C5+hydrocarbons, in total, at an aggregate concentration of  $\geq 50$  wt %, based on the total weight of the hydrocarbon feed.

[0024] An olefins production plant useful in the processes of this disclosure can comprise one or more steam cracker furnaces and an olefins product recovery section. A steam cracker furnace can comprises a radiant section and a convection section. A steam cracker feed comprising hydrocarbons, after optional combining with dilution steam, upon pre-heating in heat exchangers, e.g., in the convection section of the steam cracker furnace, is fed into a plurality of radiant tubes (also known as “radiant coils”) located in the radiant section of the steam cracker furnace. The radiant coils are heated by the thermal energy produced by combustion of a steam cracker fuel to an elevated temperature. Inside the radiant coils, the first hydrocarbon feed is subjected to steam cracking conditions including various steam cracking temperatures and various residence times, whereby the hydrocarbons undergo pyrolysis reactions to produce a steam cracker effluent exiting the steam cracker furnace comprising desirable olefins such as ethylene and propylene. Inside the radiant coils, coke may be formed and deposited on the inner surface of the radiant coils. The steam cracker effluent can be immediately quenched to stop additional undesirable reactions. The quenched cracker effluent can be separated into fractions, including a process gas stream rich in hydrogen and C1-C4 hydrocarbons. The process gas stream can be supplied to the olefins product recovery section, where the various components are separated to produce the desirable products, e.g., an ethylene product stream, a propylene product stream, and the like. An ethane stream and/or a propane stream may be produced from the process gas stream as well, which may be recycled to the steam cracker as a portion of the steam cracker hydrocarbon feed. The steam cracker furnace may be designed to crack a hydrocarbon feed rich in ethane, propane, naphtha, gas oil, or even crude oil. Switching a steam cracker designed to crack a C5+-hydrocarbon-rich steam cracker feed to crack an ethane-rich steam cracker feed or a propane-rich steam cracker feed is not easy.

[0025] It has been surprisingly and unexpectedly discovered that one or more hydrocarbon feeds containing ethane and/or propane can be subjected to steam cracking conditions within one or more radiant coils disposed within a steam cracking furnace to produce a steam cracker effluent, where a conversion of at least one of ethane, if present at a molar concentration in the first hydrocarbon feed equal to or greater than that of propane, to one or more other compounds can be  $>75\%$ , or a conversion of propane, if present at a molar concentration in the first hydrocarbon feed higher than

that of ethane feed, to one or more other compounds can be >93%, while coke produced during the steam cracking can be sufficiently removed during a decoking process such that the coke does not appreciably build-up so that the steam cracker does not require frequent (if at all) shut downs due to coke build-up that necessitates the mechanical removal of the coke build-up from within the radiant coils and/or steam cracker effluent quench exchangers. In some embodiments, steam cracking the one or more hydrocarbon feeds can be carried out within the plurality of radiant coils such that a steam cracker effluent can be produced for months, e.g., >1 month, >2 months, >3 months, >4 months, >5 months, >6 months, >8 months, or >12 months, with periodic decoking operations occurring within all of the radiant coils at the same time or with periodic decoking operations occurring within at least one of the radiant coils while maintaining steam cracking of the first hydrocarbon feed within at least one other of the radiant coils without the need to shut down the steam cracker to mechanically remove coke built up on the inner surfaces of the radiant coils and/or the inner surfaces of one or more quench exchangers. In those embodiments where online decoking with respect to one or more of the radiant coils is carried out, the run-length between offline decoking of the entire furnace can be substantially extended.

[0026] In some embodiments, the one or more hydrocarbon feeds can include one or more relatively low molecular weight hydrocarbon (light feedstocks), particularly those aspects where relatively high yields of C.sub.2 unsaturates, e.g., ethylene and acetylene, and/or C.sub.3 unsaturates, e.g., propylene and methylacetylene, can be desired. Light feedstocks can include substantially saturated hydrocarbon molecules having fewer than five carbon atoms, e.g., ethane, propane, and mixtures thereof (e.g. ethane-propane mixtures or "E/P mix"). For ethane cracking, a concentration of ethane in the first hydrocarbon feed can be, e.g., ≥50 wt %, ≥60 wt %, ≥70 wt %, ≥75 wt %, ≥80 wt %, ≥85%, ≥90 wt %, ≥95 wt %, up to 100 wt %. For propane cracking, a concentration of propane in the first hydrocarbon feed can be, e.g., ≥50 wt %, ≥60 wt %, ≥70) wt %, ≥75 wt %, ≥80 wt %, ≥85%. ≥90 wt %, ≥95 wt %, up to 100 wt %. For E/P mix, a total concentration of ethane plus propane of ≥50 wt %, ≥60 wt %, ≥70 wt %, ≥75 wt %, ≥80 wt %, ≥85%, ≥90 wt %, ≥95 wt %, up to 100 wt % can be used, the amount of ethane in the E/P mix can be >20 wt % based on the weight of the E/P mix, e.g., of about 25 wt % to about 75 wt %. The amount of propane in the E/P mix can be, e.g., ≥20 wt %, based on the weight of the E/P mix, such as of about 25 wt % to about 75 wt %. In some embodiments, the first hydrocarbon feed can be or can include, but is not limited to, a refinery gas stream that can include one or more C.sub.2 to C.sub.5, saturated or unsaturated hydrocarbons. In some embodiments, a first hydrocarbon feed can include primarily ethane, propane, or a mixture thereof, and a second hydrocarbon feed can include a refinery gas stream.

[0027] In some embodiments, the steam cracking conditions can include a residence time of, e.g., from 0.01 seconds(s), 0.02 s, 0.03 s, 0.04 s, to 0.05 s, 0.06 s, 0.07 s, 0.08 s, 0.09 s, to 0.1 s, 0.2 s, 0.3 s, 0.4 s, to 0.5 s. In some embodiments, the steam cracking conditions can include heating the first hydrocarbon feed within the radiant coils sufficiently to produce a steam cracker effluent that can have a coil outlet temperature of, e.g., from 815° C., 820° C., 825° C., 830° C., to 840° C. 850° C. 860° C. 870° C., 880° C., to 890° C., 900° C., 910° C. 920° C., or 925° C. Generally, to achieve a given conversion of ethane, the higher the coil outlet temperature, the shorter the required residence time. Likewise, to achieve a given conversion of propane, the higher the coil outlet temperature, the shorter the required residence time.

[0028] In some embodiments, introduction of the first hydrocarbon feed into at least one of the radiant coils in the plurality of radiant coils can be stopped periodically. During this periodic stoppage in the introduction of the first hydrocarbon feed, a decoking feed that includes steam or a mixture of air and steam can be introduced into the at least one of the radiant coils under decoking process conditions to remove at least a portion of any coke disposed on the inner walls of the at least one radiant coil and/or at least a portion of any coke disposed on an inner wall of one or more quench exchanger inlets in fluid communication with the at least one radiant coil. In some

embodiments the decoking feed can include, e.g., from 50 wt %, 55 wt %, 60 wt %, 65 wt %, to 70 wt %, 75 wt %, 80 wt %, 85 wt %, to 90 wt %, 95 wt %, or 100 wt % of steam, based on a combined weight of steam and the optional air.

[0029] In some embodiments, the decoking process conditions can include introducing the decoking feed (e.g., a decoking feed comprising a mixture of steam and air) into the at least one of the radiant coils to produce a decoking effluent that can have a coil outlet temperature of  $>900^{\circ}\text{C}$ . In some embodiments, the decoking effluent can have a temperature of, e.g., from  $910^{\circ}\text{C}$ ,  $920^{\circ}\text{C}$ ,  $930^{\circ}\text{C}$ ,  $940^{\circ}\text{C}$ ,  $950^{\circ}\text{C}$ , to  $960^{\circ}\text{C}$ ,  $970^{\circ}\text{C}$ ,  $980^{\circ}\text{C}$ ,  $990^{\circ}\text{C}$ ,  $1000^{\circ}\text{C}$ , to  $1010^{\circ}\text{C}$ ,  $1020^{\circ}\text{C}$ ,  $1030^{\circ}\text{C}$ ,  $1040^{\circ}\text{C}$ , or  $1050^{\circ}\text{C}$ .

[0030] In some embodiments, the decoking process conditions can include introducing the decoking feed (e.g., a decoking feed comprising steam and air) into the at least one of the radiant coils or into one or more quench exchanger inlets in fluid communication with the at least one of the radiant coils at a mass flux rate at the quench exchanger inlet of  $>39\text{ kg.Math.m.sup.}$

$-2.\text{Math.second.sup.}-1$ . In some embodiments, the decoking feed can have a mass flux rate at the quench exchanger inlet of, e.g., from 40, 42, 44, 45, to 46, 48, 50, to 52, 54, 55, to 56, 58, 60,  $\text{kg.Math.m.sup.}-2.\text{Math.second.sup.}-1$ , when introduced into the at least one of the radiant coils and/or into the one or more quench exchanger inlets.

[0031] In some embodiments, the decoking process conditions can include introducing the decoking feed (e.g., steam only) into the at least one of the radiant coils while maintaining introduction of the first hydrocarbon feed into one or more of the other radiant coils in the plurality of radiant coils. Such decoking process conditions can be referred to as “online decoking process conditions,” where steam cracking of the first hydrocarbon feed continues within one or more radiant coils while decoking conditions are present within one or more radiant coils. In some embodiments, the decoking effluent can have a coil outlet temperature of  $\leq 900^{\circ}\text{C}$ . In other embodiments, the decoking effluent can have a coil outlet temperature of  $>900^{\circ}\text{C}$ . In some embodiments, the decoking feed can be at a pressure of  $\geq 690\text{ kPa-gauge}$ ,  $\geq 750\text{ kPa-gauge}$ ,  $\geq 800\text{ kPa-gauge}$ ,  $\geq 850\text{ kPa-gauge}$ ,  $\geq 900\text{ kPa-gauge}$ , or  $\geq 930\text{ kPa-gauge}$  when introduced into the radiant coils. In some embodiments, steam cracking the one or more hydrocarbon feeds can be carried out within the plurality of radiant coils disposed within a furnace of the steam cracker such that a steam cracker effluent can be continuously produced for months, e.g.,  $\geq 1\text{ month}$ ,  $\geq 2\text{ months}$ ,  $\geq 3\text{ months}$ ,  $\geq 4\text{ months}$ ,  $\geq 5\text{ months}$ ,  $\geq 6\text{ months}$ ,  $\geq \text{months}$ ,  $\geq 20\text{ months}$ ,  $\geq 40\text{ months}$ ,  $\geq 60\text{ months}$ ,  $\geq 80\text{ months}$ , or  $\geq 100\text{ months}$ , without the need to shut down the steam cracker to mechanically remove coke built up on the inner surfaces of the radiant coils and/or the inner surfaces of one or more quench exchangers. In some embodiments, the online decoking process can include the decoking process described in WO Publication No. WO 2020/191253.

[0032] In some embodiments, the decoking process conditions can include a combination of introducing the decoking feed into the at least one of the radiant coils to produce a decoking effluent that can have a coil outlet temperature of  $>900^{\circ}\text{C}$ . and introducing the decoking feed into the at least one of the radiant coils or into one or more quench exchanger inlets in fluid communication with the at least one of the radiant coils at a mass flux rate at the quench exchanger inlet of  $>39\text{ kg.Math.m.sup.}-2.\text{Math.second.sup.}-1$ . In other embodiments, the decoking process conditions can include a combination of introducing the decoking feed into the at least one of the radiant coils to produce a decoking effluent that can have a coil outlet temperature of  $>900^{\circ}\text{C}$ . and introducing the decoking feed into the at least one of the radiant coils while maintaining introduction of the first hydrocarbon feed into one or more of the radiant coils in the plurality of radiant coils. In other embodiments, the decoking process conditions can include a combination of introducing the decoking feed into the at least one of the radiant coils or into one or more quench exchanger inlets in fluid communication with the at least one of the radiant coils at a mass flux rate at the quench exchanger inlet of  $>39\text{ kg.Math.m.sup.}-2.\text{Math.second.sup.}-1$  and introducing the decoking feed into the at least one of the radiant coils while maintaining introduction of the first

hydrocarbon feed into one or more of the radiant coils in the plurality of radiant coils. In still other embodiments, the decoking process conditions can include a combination of introducing the decoking feed into the at least one of the radiant coils to produce a decoking effluent that can have a coil outlet temperature of  $>900^{\circ}\text{C}$ ., introducing the decoking feed into the at least one of the radiant coils or into one or more quench exchanger inlets in fluid communication with the at least one of the radiant coils at a mass flux rate at the quench exchanger inlet of  $>39\text{ kg.Math.m.sup.}-2.\text{Math.second.sup.}-1$ , and introducing the decoking feed into the at least one of the radiant coils while maintaining introduction of the first hydrocarbon feed into one or more of the radiant coils in the plurality of radiant coils.

[0033] In the process of this disclosure, during the cracking interval under steam cracking conditions including an ethane conversion  $>75\%$  or a propane conversion  $>93\%$ , the steam cracking condition provides a coking severity; and during the offline decoking interval under decoking conditions, the decoking conditions provide a decoking severity. In certain embodiments, preferably the decoking severity exceeds the coking severity.

[0034] In some embodiments, the process for steam cracking hydrocarbons can include (C) operating the olefins production plant by (C1) first introducing a reference hydrocarbon feed (which may be the same as or different from the first hydrocarbon feed as described above) into the plurality of radiant coils under reference steam cracking conditions that produce a reference steam cracker effluent and convert ethane, if present at an equal or higher molar concentration than propane in the reference hydrocarbon feed, to one or more other compounds at  $<75\%$ , or propane, if present at higher concentration than ethane in the reference hydrocarbon feed, to one or more other compounds at  $<93\%$ ; and (D) adjusting step (C) to carry out step (B) by, e.g., adjusting the steam cracking conditions such that the conversion of at least one of ethane, if present at an equal or higher molar concentration than propane in the reference hydrocarbon feed, to one or more other compounds is  $\geq 75\%$ , and propane, if present at higher concentration than ethane in the reference hydrocarbon feed, to one or more other compounds is  $\geq 93\%$ .

[0035] In some embodiments, in step (C1), the first hydrocarbon feed is introduced into the plurality of radiant coils at a first quantity, in step (B1), the reference hydrocarbon feed is introduced into the plurality of radiant coils at a second quantity, the first hydrocarbon feed and the reference hydrocarbon feed have the same composition, and the second quantity is higher than the first quantity. Thus by adjusting the reference steam cracking conditions to the above described steam cracking conditions, and accordingly increasing ethane conversion from below  $75\%$  to at least  $75\%$ , or increasing propane conversion from below  $93\%$  to at least  $93\%$ , the olefins production plant processes an increased quantity of the first hydrocarbon feed without decreasing the run-length of the steam cracker furnace between adjacent decoking events requiring costly mechanical cleaning, achieving a higher productivity and reducing the associated potential dangers of mechanical cleaning.

[0036] In other embodiments, the first hydrocarbon feed may be different from the reference hydrocarbon feed, the quantity of ethane in the first hydrocarbon feed introduced into the plurality of radiant coils in step (B1) is higher than the quantity of ethane in the reference hydrocarbon feed introduced into the plurality of radiant coils in step (C1); and/or the quantity of propane in the first hydrocarbon feed introduced into the plurality of radiant coils in step (B1) is higher than the quantity of propane in the reference hydrocarbon feed introduced into the plurality of radiant coils in step (C1). In some of these embodiments, the first hydrocarbon feed can comprise ethane and/or propane at a higher concentration than the reference hydrocarbon feed. Thus by adjusting the reference steam cracking conditions to the above described steam cracking conditions, and accordingly increasing ethane conversion from below  $75\%$  to at least  $75\%$ , or increasing propane conversion from below  $93\%$  to at least  $93\%$ , the olefins production plant can be adjusted from processing a reference hydrocarbon feed comprising a relatively low concentration of ethane/propane, such as a naphtha feed or a gas oil feed, to processing a gas feed such as ethane



and/or propane, without being constrained by the capacity of the recovery section, if the recovery section was originally designed to receive process gas produced by cracking liquid feeds. Thus, in some embodiments, the reference hydrocarbon feed may consist essentially of C<sub>5</sub>+ hydrocarbons such as naphtha, gas oil, and the like. Liquid cracking steam cracker furnaces produce some recycle ethane (~4 wt %) that must be separated, while for the same amount of ethylene gas cracking plants produce more than double (~20-35 wt %) the recycle ethane. Therefore, a liquid cracker moving from all liquid feed to all gas feed will require a substantial reduction in recycle ethane from gas cracking. By increasing conversion, the recycle ethane rates are reduced and more gas cracking can be afforded to a recycle ethane or gas processing constraint.

[0037] In other embodiments where step (C) is carried out before step (B), step (B) may further comprises: (B4) separating a process gas stream comprising C<sub>1</sub>-C<sub>4</sub> hydrocarbons from the first steam cracker effluent; (B5) providing a second C<sub>1</sub>-C<sub>4</sub>-hydrocarbon-containing stream separate from the process gas stream; and (B6) supplying the process gas stream and the second C<sub>1</sub>-C<sub>4</sub>-hydrocarbon-containing stream into the olefins production recovery section. In certain embodiments, the second C<sub>1</sub>-C<sub>4</sub>-hydrocarbon-containing stream may be obtained from, e.g., a petroleum refinery facility. In these embodiments, as a result of adjusting the reference cracking conditions in step (C) and implementing step (B), less ethane is present in the process gas stream fed into the recovery section, freeing a portion of the capacity of the recovery section to receive and process a second C<sub>1</sub>-C<sub>4</sub>-hydrocarbon-containing stream, from which valuable products can be recovered.

[0038] In some embodiments, adjusting the steam cracking conditions can provide an increased production capability of ethylene, propylene, or a mixture thereof. In other embodiments, adjusting the steam cracking conditions can provide a capability of introducing or, if already introducing, increasing a throughput capability of one or more other hydrocarbons that produce ethane, propane, or a mixture thereof upon steam cracking for recycle into the plurality of radiant coils. In other embodiments, adjusting the steam cracking conditions can provide a capability of introducing or, if already introducing, increasing a throughput capability of one or more refinery gases that can include one or more saturated C<sub>sub.1</sub>-C<sub>sub.4</sub> hydrocarbons, one or more unsaturated C<sub>sub.1</sub>-C<sub>sub.4</sub> hydrocarbons, or a mixture thereof that can be introduced into the plurality of radiant coils. In still other embodiments, adjusting the steam cracking conditions can provide any combination of these benefits.

[0039] In some embodiments, in addition to or in lieu of the decoking conditions, an inner surface of the radiant coils in the plurality of radiant coils and/or an inner surface within one or more quench exchangers can include a material that is non-catalytic to coke generation. In some embodiments, the radiant coils can be alumina former tubes made of an alloy that can include ≥1.5 wt % of aluminum that have an aluminum oxide layer disposed on the inner surfaces thereof. In other embodiments, the radiant coils can include a layer comprising silicon carbide, spinel, or a combination thereof disposed on the inner surfaces thereof. In other embodiments, the radiant coils can include a layer comprising a spinel-type oxide layer disposed on the inner surfaces thereof. The spinel-type oxide layer can be or can include, but is not limited to, compounds having the chemical formula: Mn<sub>sub.x</sub>Cr<sub>sub.3-x</sub>O<sub>sub.4</sub>, wherein x is from 0.5 to 2, and from 60 wt % to 40 wt % of oxides of Mn and Si selected from the group consisting of MnO, MnSiO<sub>sub.3</sub>, Mn<sub>sub.2</sub>SiO<sub>sub.4</sub> and mixtures thereof provided that the surface contains less than 5 wt % of Cr<sub>sub.2</sub>O<sub>sub.3</sub>.

[0040] In some embodiments, the process of this disclosure can comprise: (1) providing an olefins production plant comprising a steam cracking furnace and an olefins product recovery section; (2) operating the olefins production plant by: (2a) in a cracking interval, introducing a first hydrocarbon feed comprising at least one of ethane and propane into a plurality of radiant coils disposed within the steam cracking furnace under first steam cracking conditions that produce a first steam cracker effluent and deposit coke on an inner surface of the radiant coils, wherein a conversion of ethane, if present at a molar concentration in the first hydrocarbon feed equal to or

greater than that of propane, to one or more other compounds is  $\geq 75\%$ , or a conversion of propane, if present at a molar concentration in the first hydrocarbon feed higher than that of ethane feed, to one or more other compounds is  $\geq 93\%$ ; (2b) optionally conducting online decoking in an online decoking interval of at least one of the radiant coils by introducing a decoking steam there into; (2c) periodically stopping introduction of the first hydrocarbon feed into at least one of the radiant coils in the plurality of radiant coils; and (3) providing a reference process comprising: (3a) in a reference cracking interval, introducing a reference steam cracker feed (preferably the same as the first hydrocarbon feed) into the plurality of radiant coils under reference steam cracking conditions that produce a reference steam cracker effluent and deposit coke on the inner surface of the radiant coils, having a reference conversion of ethane, if present, to one or more other compounds of  $\leq 75\%$ , and a reference conversion of propane, if present, to one or more other compounds of  $\leq 93\%$ ; (3b) periodically stopping introduction of the reference steam cracker feed into at least one of the radiant coils in the plurality of radiant coils; and (3c) in a reference offline decoking interval, introducing the decoking feed into the at least one of the radiant coils under reference decoking conditions, (4) introducing a decoking feed comprising steam and optionally air into the at least one of the radiant coils under decoking process conditions such that  $[0041] -2 \text{ mm} \leq AA \leq 2 \text{ mm}$ , where [00002]

$AA = R1(\text{ref}) * D1(\text{ref}) + R(\text{ref}) * \text{delta}(D1) + \text{delta}(R1) * (D1(\text{ref}) + \text{delta}(D1)) - P1 - (P2 - P2(\text{ref}))$ ; [0042]  $\text{delta}(R1) = R1 - R1(\text{ref})$ , where R1 is average coke deposition rate in the radiant coils in the process during the cracking interval, in  $\text{mm day.sup.-1}$ , and R1(ref) is average coke deposition rate in the radiant coils in the reference process during the reference cracking interval, in  $\text{mm.Math.day.sup.-1}$ ; [0043] D1(ref) is the duration of the reference cracking interval, in days; [0044]  $\text{delta}(D1) = D1 - D1(\text{ref})$ , where D1 is duration of the cracking interval, in days; [0045] P1 is coke removed during the online decoking interval, if any, in mm; [0046] P2 is coke removed during the offline decoking interval, in mm; and [0047] P2 (ref) is coke removed during the reference offline decoking interval, in mm.

[0048] In some embodiments, the reference process in step (3) may have been carried out at the olefins production plant prior to step (2). In such case P2(ref) can be measured. P1 and P2 can be measured. In some embodiments, the reference hydrocarbon feed has substantially the same composition as the first hydrocarbon feed. We have found that, by adjusting the reference steam cracking conditions in step (3) to the steam cracking conditions in step (2), thus achieving an elevated ethane conversion  $> 75\%$  and/or a propane conversion  $\geq 93\%$ , a low coke layer thickness change, AA,  $-2 \text{ mm} \leq AA \leq 2 \text{ mm}$ , can be realized, thus achieving a prolonged run-length of the steam cracker furnace between adjacent mechanical cleaning of the radiant coils, which can be costly and potentially dangerous. Preferably,  $-1 \text{ mm} \leq AA \leq 1 \text{ mm}$ . Preferably,  $-0.5 \text{ mm} \leq AA \leq 0.5 \text{ mm}$ .

[0049] In some embodiments, the process above can comprise, in addition to steps (1), (2), (3), and (4), the following: (5) during a plurality of quench exchanger decoking intervals, feeding a quench exchanger decoking feed into a quench exchanger inlet tube operated under quench exchanger decoking conditions: [0050] wherein: [0051] the reference process further comprises: during a plurality of reference quench exchanger decoking intervals, feeding the quench exchanger decoking feed into the quench exchanger inlet tube operated under reference quench exchanger decoking conditions: [0052] the process further comprises selecting the quench exchanger decoking conditions such that: [0053]  $-2 \text{ mm} \leq BB = \text{delta}(R2) * (D2(\text{ref}) + \text{delta}(D2)) - (P3 - P3(\text{ref})) \leq 2 \text{ mm}$ , where: [0054]  $\text{delta}(R2) = R2 - R2(\text{ref})$ , where R2 is average coke deposition rate in the quench exchanger inlet tube between two adjacent quench exchanger decoking intervals, in  $\text{mm day.sup.-1}$ ; and R2(ref) is average coke deposition rate in the quench exchanger inlet tube in the reference process between two adjacent reference quench exchanger decoking intervals, in  $\text{mm.Math.day.sup.-1}$ ; [0055] D2 (ref) is the duration between two adjacent quench exchanger decoking intervals, in days; [0056]  $\text{delta}(D2) = D2 - D2(\text{ref})$ , where D2 is the duration between two

adjacent quench exchanger decoking intervals, in days; [0057] P3 is average coke removed during the plurality of quench exchanger decoking intervals, in mm; and [0058] P3 (ref) is average coke removed during the plurality of reference quench exchanger decoking intervals, in mm. [0059] P3 and P3(ref) can be measured. BB represents the change of coke deposition in the quench exchanger in step (5) relative to the reference process. Preferably,  $-1.5\text{ mm} \leq \text{BB} \leq 0.5\text{ mm}$ . Preferably,  $-1\text{ mm} \leq \text{BB} \leq 15\text{ mm}$ . Preferably  $-0.5\text{ mm} \leq \text{BB} \leq 0.5\text{ mm}$ . By adjusting the reference steam cracking conditions in step (3) to the steam cracking conditions in step (2), thus achieving an elevated ethane conversion  $\geq 75\%$  and/or a propane conversion  $\geq 93\%$ , and selecting the quench exchanger decoking conditions, a low coke layer change BB in the quench exchanger,  $-2\text{ mm} \leq \text{BB} \leq 2\text{ mm}$ , can be realized, thus achieving a prolonged run-length of the quench exchanger between adjacent mechanical cleaning of the quench exchanger, which can be costly and potentially dangerous. [0060] Similarly, the process of this disclosure comprising steps (1), (2), (3), (4), and optionally step (5) can comprise one or more of the following: (i) introducing the decoking feed into the at least one of the radiant coils to produce a decoking effluent having a coil outlet temperature of  $>900^\circ\text{C}$ .; (ii) introducing the decoking feed into the at least one of the radiant coils or into one or more quench exchanger inlets in fluid communication with the at least one of the radiant coils at a mass flux rate at the quench exchanger inlet of  $>39\text{ kg.Math.m.sup.-2, second.sup.-1}$ ; and (iii) introducing the decoking feed into the at least one of the radiant coils while maintaining introduction of the first hydrocarbon feed into one or more of the radiant coils in the plurality of radiant coils.

[0061] The FIGURE depicts a schematic of an illustrative steam cracking furnace **100** in operation to convert a first hydrocarbon feed in line **1001** and a second hydrocarbon feed in line **1003**, within one or more first radiant coils **1025** and within one or second radiant coils **1027**, respectively, disposed within a radiant section **1029** of the steam cracking furnace **100**, according to one or more embodiments. A feed rate of the first hydrocarbon feed in line **1001** can be controlled via a first flow control device **1002** and a feed rate of the second hydrocarbon feed in line **1003** can be controlled via a second flow control device **1004**.

[0062] In some embodiments, the composition of the first hydrocarbon feed in line **1001** and the composition of the second hydrocarbon feed in line **1003** can be the same or different with respect to one another. In some embodiments, at least one of the first hydrocarbon feed in line **1001** and the second hydrocarbon feed in line **1003** can include ethane, propane, or a mixture thereof. In some embodiments, the first hydrocarbon feed in line **1001** and the second hydrocarbon feed in line **1003** can each include ethane, propane, or a mixture thereof. In some embodiments, the first hydrocarbon feed in line **1001** and/or the second hydrocarbon feed in line **1003** can include 30 wt %, 40 wt %, 50 wt %, 60 wt %, 70 wt %, 75%, 80 wt %, 85 wt %, 90 wt %, 95 wt %, or more of ethane, based on a total weight of all hydrocarbons in the first hydrocarbon feed. In other embodiments, the first hydrocarbon feed in line **1001** and/or the second hydrocarbon feed in line **1003** can include 30 wt %, 40 wt %, 50 wt %, 60 wt %, 70 wt %, 75%, 80 wt %, 85 wt %, 90 wt %, 95 wt %, or more of propane, based on a total weight of all hydrocarbons in the first hydrocarbon feed. In some embodiments, the first hydrocarbon feed in line **1001** and the second hydrocarbon feed in line **1003** can include a mixture of ethane and propane. For example, a hydrocarbon feed that includes ethane and propane can include at least 75 wt % of a combined amount of ethane and propane, based on a total weight of the first hydrocarbon feed, where the amount of ethane in the ethane and propane mixture can be  $\geq 20\text{ wt \%}$  based on the combined weight of the ethane and propane in the first hydrocarbon feed. In another example, a hydrocarbon feed that includes ethane and propane can include at least 75 wt % of a combined amount of ethane and propane, based on a total weight of the first hydrocarbon feed, where the amount of propane in the ethane and propane mixture can be  $\geq 20\text{ wt \%}$ , based on the combined weight of the ethane and propane in the first hydrocarbon feed.

[0063] In some embodiments, the first hydrocarbon feed in line **1001** and the second hydrocarbon feed in line **1003** can be mixed, blended, combined, or otherwise contacted with steam in lines

**1007** and **1009**, respectively, to produce first and second hydrocarbon and steam mixtures in lines **1011** and **1013**, respectively. In some embodiments, the first and second hydrocarbon and steam mixtures can independently include steam in an amount in of about 10 wt % to about 95 wt %, based on the weight of the hydrocarbon and steam mixture. As shown, the steam in lines **1007** and **1009** can be provided from a common source, e.g., steam in line **1005**. In other embodiments, the steam in lines **1007** and **1009** can be provided from different sources. A feed rate of the steam contacted with the first hydrocarbon feed in line **1001** can be controlled by a third flow control device **1008** and a feed rate of the steam contacted with the second hydrocarbon feed in line **1003** can be controlled by a fourth flow control device **1010**. The amount of steam contacted with the first and second hydrocarbon feeds in lines **1001** and **1003** can be the same or different with respect to one another.

[0064] The first and second mixtures in lines **1011** and **1013** can each be heated within one or more convection coils **1015** and **1017**, respectively, disposed within the convection section **1019** of the steam cracking furnace **100** to produce first and second heated mixtures via lines **1021** and **1023**, respectively. In some embodiments, the first and second mixtures in lines **1011** and **1013** can be heated to a temperature of 200° C., 300° C., 400°, or 450° C. to 500° C., 600° C., 700° C., or 750° C. within the convection section **1019**. The first and second heated mixtures in lines **1021** and **1023** can be further heated and subjected to steam cracking conditions within the one or more first radiant coils **1025** and within the one or more second radiant coils **1027**, respectively, disposed within the radiant section **1029** of the steam cracking furnace **100** to produce first and second steam cracker effluents via lines **1031** and **1033**, respectively.

[0065] The first radiant coil(s) **1025** and the second radiant coil(s) **1027** can be heated by a plurality of burners (four are shown—**1035**, **1037**, **1039**, and **1041**). The burners **1035** and **1037** can be considered as being disposed within a first segment of the radiant section **1029** and the burners **1039** and **1041** can be considered as being disposed within a second segment of the radiant section **1029**. As such, the first segment of the radiant section occupies the left half of the radiant section **1029** and the second segment of the radiant section **1029** occupies the right half of the radiant section **1029**, as shown in the FIGURE. In some embodiments, during operation, the burners **1035**, **1037**, **1039**, and **1041** can be operated at substantially the same firing rate such that the amount of heat produced by each burner in the first and second segments is substantially the same. In other embodiments, during operation, one or more of the burners **1035**, **1037**, **1039**, and **1041** can be operated at different firing rates with respect to one or more other burners such that the amount of heat produced by each burner is not substantially the same.

[0066] In some embodiments, the first steam cracker effluent in line **1031** can have a first coil outlet temperature upon exiting the first radiant coil(s) **1025** and the second steam cracker effluent in line **1033** can have a second coil outlet temperature upon exiting the second radiant coil(s) **1027**. The first coil outlet temperature of the first steam cracker effluent in line **1031** can be measured with a first temperature measuring device, e.g., thermocouple, **1043** and the second coil outlet temperature of the second steam cracker effluent in line **1033** can be measured with a second temperature measuring device, e.g., thermocouple, **1045**.

[0067] In some embodiments, the feed rate of the first hydrocarbon feed in line **1001** and the feed rate of the second hydrocarbon feed in line **1003** can be controlled based, at least in part, on the composition(s) of the first and second hydrocarbon feeds and/or the first and second coil outlet temperatures, respectively. In some embodiments, the feed rate of the first hydrocarbon feed in line **1001** can be reduced to increase the first coil outlet temperature of the first steam cracker effluent in line **1031**. In other embodiments, the feed rate of the first hydrocarbon feed in line **1001** can be increased to reduce the first coil outlet temperature of the first steam cracker effluent in line **1031**. The feed rate of the second hydrocarbon feed in line **1003** can be controlled in a similar manner as the feed rate of the first hydrocarbon feed in line **1001**.

[0068] Similar to the feed rates of the first and second hydrocarbon feeds, the feed rate of the steam

in line **1007** and the steam in line **1009** that can be contacted with the first hydrocarbon feed in line **1001** and the second hydrocarbon feed in line **1003**, respectively, can be controlled based, at least in part, on the composition(s) of the first and second hydrocarbon feeds and the first and second coil outlet temperatures, respectively. By controlling the feed rate of the first and second hydrocarbon feeds and the steam contacted therewith, the feed rate of the heated first and second hydrocarbon feeds introduced via lines **1021** and **1023**, respectively, can be increased or decreased as desired to control or otherwise adjust the first coil outlet temperature and the second coil outlet temperature as desired.

[0069] In other embodiments, the feed rate of the first hydrocarbon feed in line **1001** and the feed rate of the second hydrocarbon feed in line **1003**, which can be the same or different with respect to one another, can remain substantially constant during steam cracking. In such embodiment, the amount of heat produced via the burners **1035**, **1037**, **1039**, and **1041** can be independently adjusted to control or otherwise adjust the coil-outlet-temperatures of the first and second steam cracker effluents in lines **1031** and **1033**. The feed rate of the steam in line **1007** and the steam in line **1009** that can be contacted with the first hydrocarbon feed in line **1001** and the second hydrocarbon feed in line **1003**, respectively, which can be the same or different with respect to one another, can also remain substantially the same or can be independently adjusted with respect to one another during steam cracking.

[0070] In some embodiments, the steam cracking conditions can include, but are not limited to, one or more of: exposing the heated mixtures of the first hydrocarbon feed and steam in line (or a vapor phase product separated therefrom) to a temperature (as measured at a radiant outlet of the steam cracking furnace) of  $\geq 400^{\circ}\text{C}$ ., e.g., a temperature of about  $700^{\circ}\text{C}$ ., about  $800^{\circ}\text{C}$ . or about  $900^{\circ}\text{C}$ . to about  $950^{\circ}\text{C}$ ., about  $1,000^{\circ}\text{C}$ ., or about  $1050^{\circ}\text{C}$ ., a pressure of about 10 kPa-absolute to about 500 kPa-absolute or more, and/or a steam cracking residence time of about 0.01 second to about 5 seconds, preferably from 0.01 second to 1 second, preferably from 0.01 second to 0.5 second.

[0071] In some embodiments, the steam cracking conditions can be sufficient produce a steam cracker effluent and deposit coke on an inner surface of the radiant coils **1025**, **1027**, where a conversion of at least one of ethane, if present at higher concentration than propane in the hydrocarbon feed, to one or more other compounds is  $>75\%$ , and a conversion of propane, if present at higher concentration than ethane in the hydrocarbon feed, to one or more other compounds is  $>93\%$ . Periodically the introduction of the first hydrocarbon feed in line **1001** and/or introduction of the second hydrocarbon feed in line **1003** can be stopped by closing the flow control device **1002** and/or **1010**, respectively.

[0072] A decoking feed that can include steam or a mixture of air and steam can be introduced into the first and/or second radiant coil(s) **1025**, **1027** that does not have the first and/or second hydrocarbon feed being introduced thereto. In some embodiments, when the flow control device **1002** is closed, flow control device **1012** can be opened such that air (or other oxidant) in line **1006** can be mixed, blended, combined, or otherwise contacted with the steam in line **1007** to produce the decoking feed that can flow through the radiant coil **1025** to produce a decoking effluent in line **1031**. In some embodiments, the decoking effluent in line **1031** can be at a temperature of  $>900^{\circ}\text{C}$ ., can be introduced into the radiant coil **1025** and/or a quench exchanger inlet **1049** of a quench exchanger **1051** at a mass flux at the quench exchanger inlet of  $>39\text{ kg.Math.m.sup.}$

$-2.\text{Math.second.sup.}-1$ , introduced into the radiant coil **1025** while flow of the first hydrocarbon feed in line **1003** is maintained, or any combination thereof.

[0073] In other embodiments, when the flow control device **1004** is closed, flow control device **1018** can be opened such that air (or other oxidant) in line **1016** can be mixed, blended, combined, or otherwise contacted with the steam in line **1009** to produce the decoking feed that can flow through the radiant coil **1027** to produce a decoking effluent in line **1033**. In some embodiments, the decoking effluent in line **1033** can be at a temperature of  $>900^{\circ}\text{C}$ ., can be introduced into the radiant coil **1027** and/or a quench exchanger inlet **1049** of the quench exchanger **1051** at a mass

flux at the quench exchanger inlet of  $>39$  kg.Math.m.sup.-2.Math.second.sup.-1, introduced into the radiant coil **1027** while flow of the first hydrocarbon feed in line **1001** is maintained, or any combination thereof.

[0074] In some embodiments, one or more quench mediums via line **1047** can be introduced into the inlet **1049** of the quench exchanger **1051** and can contact the decoking effluent, and if present, steam cracker effluent to produce a cooled effluent via line **1053**. In other embodiments, the quench exchanger **1051** can be an indirect heat exchange stage such that heat can be indirectly transferred from the decoking effluent, and if present, steam cracker effluent to produce the cooled effluent via line **1053**. In still other embodiments, the quench exchanger **1051** can include a direct contact exchange stage and an indirect heat exchange stage.

[0075] In some embodiments, the quench medium in line **1047** that can be contacted with the steam cracker effluent and/or the decoking effluent can be or can include a utility fluid. In some embodiments, the utility fluid can be the same or similar to the utility fluids described in U.S. Pat. Nos. 9,090,836; 9,637,694; and 9,777,227; and International Patent Application Publication No. WO 2018/111574.

[0076] Suitable steam crackers, process gas recovery configurations, other equipment, and process conditions can include those disclosed in U.S. Pat. Nos. 6,419,885; 7,560,019; 7,993,435; 8,105,479; 8,197,668; 8,882,991; 9,637,694; 9,777,227; U.S. Patent Application Publication Nos.: 2014/0061096; 2014/0357923; 2016/0376511; 2018/0170832, 2019/0016975; and WO Publication No.: WO 2018/111574; WO/2020/096972; WO/2020/096974; WO/2020/096977; and WO/2020/096979. Suitable dividing walls that can optionally be disposed between two or more segments can include those disclosed in U.S. Pat. No. 7,718,052

#### Hydrocarbon Feeds

[0077] In some embodiments, the first and/or second hydrocarbon feeds in lines **1001** and **1003**, respectively, can be or can include, but are not limited to, lighter hydrocarbons such as C.sub.1-C.sub.5 alkanes, naphtha distillate, aromatic hydrocarbons, or any mixture thereof. In some embodiments, as noted above, two or more hydrocarbon feeds can be introduced into the steam cracker and the two hydrocarbon feeds can be the same or different with respect to one another. In other embodiments, the first and/or second hydrocarbon feeds in line **1001** and **1003**, respectively, can be or can include, but are not limited to, relatively high molecular weight hydrocarbons ("heavy feedstocks"), such as those that produce a relatively large amount of steam cracker tar ("SCT") during steam cracking. Examples of heavy feedstocks can include one or more of steam cracked gas oil and residues, gas oils, heating oil, jet fuel, diesel, kerosene, coker naphtha, steam cracked naphtha, catalytically cracked naphtha, hydrocrackate, reformat, raffinate reformat, Fischer-Tropsch liquids, Fischer-Tropsch gases, distillate, crude oil, atmospheric pipestill bottoms, vacuum pipestill streams including bottoms, gas oil condensates, heavy non-virgin hydrocarbon streams from refineries, vacuum gas oils, heavy gas oil, naphtha contaminated with crude, atmospheric residue, heavy residue, Ca/residue admixture, naphtha/residue admixture, gas oil/residue admixture, crude oil, or any mixture thereof.

[0078] In some embodiments, the first hydrocarbon feed in line **1001** can include one or more lighter hydrocarbons and the second hydrocarbon feed in line **1003** can include one or more heavy feedstocks. In some embodiments, the second hydrocarbon feed in line **1003** can have a nominal final boiling point  $\geq 315^{\circ}\text{C.}$ ,  $\geq 399^{\circ}\text{C.}$ ,  $\geq 454^{\circ}\text{C.}$  or  $\geq 510^{\circ}\text{C.}$  Nominal final boiling point means the temperature at which 99.5 wt % of a particular sample has reached its boiling point. Suitable hydrocarbon feeds can be or can include those described in U.S. Pat. Nos. 7,138,047; 7,993,435; 8,696,888; 9,327,260; 9,637,694; 9,657,239; and 9,777,227; and International Patent Application Publication No. WO 2018/111574.

[0079] In some embodiments, e.g., when the first and/or second hydrocarbon feeds in lines **1001** and/or **1003**, respectively, include certain heavy feedstocks, the system **100** can include one or more vapor/liquid separators (sometimes referred to as flash pot or flash drum) integrated

therewith. When used, the vapor-liquid separator can be configured to upgrade the first hydrocarbon feed, e.g., by upgrading the hydrocarbon and steam mixture, upstream of the radiant section **1029**. In some embodiments, it can be desirable to integrate the vapor-liquid separator with the furnace when the first hydrocarbon feed includes  $\geq 1$  wt % of non-volatiles, e.g.,  $\geq 5$  wt %, such as about 5 wt % to about 50 wt % of non-volatiles having a nominal boiling point of  $\geq 760^\circ\text{C}$ . In some embodiments, it can be desirable to integrate the vapor/liquid separator with the furnace when the non-volatiles include asphaltenes, such as  $\geq$ about 0.1 wt % asphaltenes based on the weight of the first hydrocarbon feed, e.g.,  $\geq$ about 5 wt %. Conventional vapor/liquid separation devices can be utilized to do this, though the process and systems disclosed herein are not limited thereto. Examples of such conventional vapor/liquid separation devices can include those disclosed in U.S. Pat. Nos. 7,138,047; 7,090,765; 7,097,758; 7,820,035; 7,311,746; 7,220,887; 7,244,871; 7,247,765; 7,351,872; 7,297,833; 7,488,459; 7,312,371; 6,632,351; 7,578,929; and 7,235,705. A vapor phase can be separated from the first hydrocarbon feed in the vapor/liquid separation device. The separated vapor phase can be conducted away from the vapor/liquid separator to the radiant coil(s) for steam cracking. The liquid-phase separated from the first hydrocarbon feed can be conducted away from the vapor/liquid separation device, e.g., for storage and/or further processing.

#### EXAMPLES

[0080] The foregoing discussion can be further described with reference to the following non-limiting examples.

[0081] In Example 1, ethane was steam cracked at a conversion to other compounds of 75% to 80% and a steam-air decoking procedure was periodically used that ensured a mass flux at the quench exchanger inlet exceeding 39 kg.Math.m.sup.-2.Math.second.sup.-1 as the steam-air mixture entered into the inlet cones of a transfer line exchanger. A steam cracking run length of 19 to 28 days between implementation of the steam-air decoking procedure was accomplished with the coke sufficiently removed during each steam-air decoking procedure such that coke build-up was avoided.

[0082] In Example 2, ethane was steam cracked at a conversion to other compounds of 75% to 82% under steam cracking run lengths that were greater than 20 days between the periodic implementation of a steam-air decoking procedure. Radiant tubes composed of alumina were installed to enable the steam cracking run lengths and a sufficient amount of coke was removed during each steam-air decoking procedure such that coke build-up was avoided.

[0083] In Example 3, ethane was steam cracked at a conversion to other compounds of 75% to 82% under steam cracking run lengths that were greater than 20 days between the periodic implementation of a steam-air decoking procedure that used a coil-outlet-temperature of  $>900^\circ\text{C}$ . The steam-air decoking procedure in this example was able to remove the coke and avoided accumulation of coke over multiple steam cracking run lengths.

[0084] In Example 4, ethane was steam cracked within a plurality of radiant coils disposed in a steam cracker and a conversion of ethane to other compounds of 80% was obtained and sustained for months. To accomplish such a long steam cracking run length an online decoking process that only implemented a steam-only decoking procedure on a portion of the radiant coils at a time while steam cracking continued in the remaining radiant coils was implemented. In other words, less than all the radiant coils underwent decoking at any given time while the other radiant coils continued to receive the first hydrocarbon feed for steam cracking. More particularly, steam-air decoking in which the steam-air decoking effluent had a temperature of  $>900^\circ\text{C}$ . was only used once during a nearly 7 month run length.

[0085] Various terms have been defined above. To the extent a term used in a claim is not defined above, it should be given the broadest definition persons in the pertinent art have given that term as reflected in at least one printed publication or issued patent. Furthermore, all patents, test procedures, and other documents cited in this application are fully incorporated by reference to the extent such disclosure is not inconsistent with this application and for all jurisdictions in which

such incorporation is permitted.

[0086] While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

## Claims

1. A process for steam cracking hydrocarbons, comprising: (A) providing an olefins production plant comprising a steam cracking furnace and an olefins product recovery section; (B) operating the olefins production plant by: (B1) introducing a first hydrocarbon feed comprising at least one of ethane and propane into a plurality of radiant coils disposed within the steam cracking furnace under first steam cracking conditions that produce a first steam cracker effluent and deposit coke on an inner surface of the radiant coils, wherein a conversion of ethane, if present at a molar concentration in the first hydrocarbon feed equal to or greater than that of propane, to one or more other compounds is  $\geq 75\%$ , or a conversion of propane, if present at a molar concentration in the first hydrocarbon feed higher than that of ethane, to one or more other compounds is  $\geq 93\%$ ; (B2) periodically stopping introduction of the first hydrocarbon feed into at least one of the radiant coils in the plurality of radiant coils; and (B3) introducing a decoking feed comprising steam and optionally air into the at least one of the radiant coils under decoking process conditions, wherein the decoking process conditions comprise at least one of: (i) introducing the decoking feed into the at least one of the radiant coils to produce a decoking effluent having a coil outlet temperature of  $>900^{\circ}\text{C.}$ ; (ii) introducing the decoking feed into the at least one of the radiant coils or into one or more quench exchanger inlets in fluid communication with the at least one of the radiant coils at a mass flux rate at the quench exchanger inlet of  $>39\text{ kg.Math.m.sup.-2.Math.second.sup.-1}$ ; and (iii) introducing the decoking feed into the at least one of the radiant coils while maintaining introduction of the hydrocarbon feed into one or more of the radiant coils in the plurality of radiant coils.
2. The process of claim 1, wherein the decoking process comprises step (B3)(i), wherein the decoking feed comprises a mixture of steam and air.
3. The process of claim 1, wherein the decoking process comprises step (B3)(ii), wherein the decoking feed comprises a mixture of steam and air.
4. The process of claim 1, wherein the decoking process comprises step (B3)(iii), wherein the decoking feed is steam.
5. The process of claim 1, wherein the steam cracking conditions comprise a residence time of the hydrocarbon feed within the radiant coils of 0.01 second to 5 seconds, heating the hydrocarbon feed within the radiant coils sufficiently to produce a steam cracker effluent having a coil outlet temperature of from  $815^{\circ}\text{C.}$  to  $925^{\circ}\text{C.}$ , or a combination thereof.
6. The process of claim 1, wherein the hydrocarbon feed comprises ethane and propane at a total concentration of no less than 75 wt %, based on the total volume of the hydrocarbon feed.
7. The process of claim 1, wherein the hydrocarbon feed comprises ethane at a concentration of no less than 75 wt %, based on the total volume of the hydrocarbon feed.
8. The process of claim 1, further comprising, before step (B): (C) operating the olefins production plant by: (C1) introducing a reference hydrocarbon feed into the plurality of radiant coils under reference steam cracking conditions that produce a reference steam cracker effluent, wherein a conversion of at least one of ethane, if present at an equal or higher molar concentration than propane in the reference hydrocarbon feed, to one or more other compounds is  $<75\%$ , and propane, if present at a higher molar concentration than ethane in the reference hydrocarbon feed, to one or more other compounds is  $<93\%$ ; and (D) adjusting step (C) to carry out step (B).
9. The process of claim 8, wherein: in step (C1), the first hydrocarbon feed is introduced into the plurality of radiant coils at a first quantity, in step (B1), the reference hydrocarbon feed is



introduced into the plurality of radiant coils at a second quantity, the first hydrocarbon feed and the reference hydrocarbon feed have the same composition, and the second quantity is higher than the first quantity.

**10.** The process of claim 8, wherein: the quantity of ethane in the first hydrocarbon feed introduced into the plurality of radiant coils in step (B1) is higher than the quantity of ethane in the reference hydrocarbon feed introduced into the plurality of radiant coils in step (C1); and/or the quantity of propane in the first hydrocarbon feed introduced into the plurality of radiant coils in step (B1) is higher than the quantity of propane in the reference hydrocarbon feed introduced into the plurality of radiant coils in step (C1).

**11.** The process of claim 8, wherein: the reference hydrocarbon feed consists essentially of C5+ hydrocarbons.

**12.** The process of claim 8, wherein: step (B) further comprises: (B4) separating a process gas stream comprising C1-C4 hydrocarbons from the first steam cracker effluent; (B5) providing a second C1-C4-hydrocarbon-containing stream separate from the process gas stream; and (B6) supplying the process gas stream and the second C1-C4-hydrocarbon-containing stream into the olefins product recovery section.

**13.** A process for steam cracking hydrocarbons, comprising: introducing a first hydrocarbon feed comprising ethane, propane, or a mixture thereof into a plurality of radiant coils disposed within a steam cracking furnace under steam cracking conditions that produce a steam cracker effluent and deposit coke on an inner surface of the radiant coils, wherein a conversion of at least one of ethane, if present at a molar concentration in the first hydrocarbon feed equal to or greater than that of propane, to one or more other compounds is  $\geq 75\%$ , or a conversion of propane, if present at a molar concentration in the first hydrocarbon feed higher than that of ethane, to one or more other compounds is  $\geq 93\%$ ; and wherein an inner surface of the radiant coils in the plurality of radiant coils comprises a material that is non-catalytic to coke generation.

**14.** The process of claim 13, wherein the radiant coils are alumina former tubes made of an alloy comprising  $\geq 1.5$  wt % of aluminum that have an aluminum oxide layer disposed on the inner surfaces thereof.

**15.** The process of claim 13, wherein the radiant coils comprise a layer comprising silicon carbide, spinel, or a combination thereof disposed on the inner surfaces thereof.

**16.** The process of claim 13, wherein the radiant coils comprise a layer comprising a spinel-type oxide layer disposed on the inner surfaces thereof.

**17.** The process of claim 16, wherein the spinel-type oxide layer comprises 40 wt % to 60 wt % of compounds having the chemical formula:  $\text{Mn}_{0.5-2}\text{Cr}_{0.3-0.4}\text{O}_{1.5-2}$ , wherein x is from 0.5 to 2, and from 60 wt % to 40 wt % of oxides of Mn and Si selected from the group consisting of  $\text{MnO}$ ,  $\text{MnSiO}_3$ ,  $\text{Mn}_2\text{SiO}_4$  and mixtures thereof provided that the surface contains less than 5 wt % of  $\text{Cr}_2\text{O}_3$ .

**18.** The process of claim 13, further comprising: periodically stopping introduction of the first hydrocarbon feed into at least one of the radiant coils in the plurality of radiant coils; and introducing a decoking feed comprising a steam and optionally air into the at least one of the radiant coils to remove at least a portion of any coke deposited on an inner surface of the at least one of the radiant coils.

**19.** The process of claim 13, wherein the first hydrocarbon feed comprises ethylene and/or propylene.

**20.** The process of claim 12, wherein the steam cracking conditions comprise a residence time of the first hydrocarbon feed within the radiant coils of 0.01 second to 5 seconds, heating the first hydrocarbon feed within the radiant coils sufficiently to produce a steam cracker effluent having a coil outlet temperature of 815° C. to 925° C., or a combination thereof.

**21.** A process for steam cracking hydrocarbons, comprising: (1) providing an olefins production plant comprising a steam cracking furnace and an olefins product recovery section; (2) operating

the olefins production plant by: (2a) in a cracking interval, introducing a first hydrocarbon feed comprising at least one of ethane and propane into a plurality of radiant coils disposed within the steam cracking furnace under first steam cracking conditions that produce a first steam cracker effluent and deposit coke on an inner surface of the radiant coils, wherein a conversion of ethane, if present at a molar concentration in the first hydrocarbon feed equal to or greater than that of propane, to one or more other compounds is  $>75\%$ , or a conversion of propane, if present at a molar concentration in the first hydrocarbon feed higher than that of ethane, to one or more other compounds is  $\geq 93\%$ ; (2b) optionally conducting online decoking in an online decoking interval of at least one of the radiant coils by introducing a decoking steam there into; (2c) periodically stopping introduction of the first hydrocarbon feed into at least one of the radiant coils in the plurality of radiant coils; and (3) providing a reference process comprising: (3a) in a reference cracking interval, introducing a reference hydrocarbon feed into the plurality of radiant coils under reference steam cracking conditions that produce a reference steam cracker effluent and deposit coke on the inner surface of the radiant coils, having a reference conversion of ethane, if present, to one or more other compounds of  $\leq 75\%$ , and a reference conversion of propane, if present, to one or more other compounds of  $\leq 93\%$ ; (3b) periodically stopping introduction of the reference hydrocarbon feed into at least one of the radiant coils in the plurality of radiant coils; and (3c) in a reference offline decoking interval, introducing the decoking feed into the at least one of the radiant coils under reference decoking conditions; (4) introducing a decoking feed comprising steam and optionally air into the at least one of the radiant coils under decoking process conditions such that  $-2 \text{ mm} \leq AA \leq 2 \text{ mm}$ , where

$AA = R1(\text{ref}) * D1(\text{ref}) + R(\text{ref}) * \text{delta}(D1) + \text{delta}(R1) * (D1(\text{ref}) + \text{delta}(D1)) - P1 - (P2 - P2(\text{ref}))$ ;  $\text{delta}(R1) = R1 - R1(\text{ref})$ , where R1 is average coke deposition rate in the radiant coils in the process during the cracking interval, in  $\text{mm.Math.day.sup.-1}$ , and R1(ref) is average coke deposition rate in the radiant coils in the reference process during the reference cracking interval, in  $\text{mm.Math.day.sup.-1}$ ; D1(ref) is the duration of the reference cracking interval, in days;  $\text{delta}(D1) = D1 - D1(\text{ref})$ , where D1 is duration of the cracking interval, in days; P1 is coke removed during the online decoking interval, if any, in mm; P2 is coke removed during the offline decoking interval, in mm; and P2(ref) is coke removed during the reference offline decoking interval, in mm.

22. The process of claim 21, wherein  $-0.5 \text{ mm} \leq AA \leq 0.5 \text{ mm}$ .

23. The process of claim 21, further comprising: (5) during a plurality of quench exchanger decoking intervals, feeding a quench exchanger decoking feed into a quench exchanger inlet tube operated under quench exchanger decoking conditions; wherein: the reference process further comprises: during a plurality of reference quench exchanger decoking intervals, feeding the quench exchanger decoking feed into the quench exchanger inlet tube operated under reference quench exchanger decoking conditions; the process further comprises selecting the quench exchanger decoking conditions such that:  $-2 \text{ mm} \leq BB \leq 2 \text{ mm}$ , where:

$BB = \text{delta}(R2) * (D2(\text{ref}) + \text{delta}D2) - (P3 - P3(\text{ref}))$ ;  $\text{delta}(R2) = R2 - R2(\text{ref})$ , where R2 is average coke deposition rate in the quench exchanger inlet tube between two adjacent quench exchanger decoking intervals, in  $\text{mm.Math.day.sup.-1}$ ; and R2(ref) is average coke deposition rate in the quench exchanger inlet tube in the reference process between two adjacent reference quench exchanger decoking intervals, in  $\text{mm.Math.day.sup.-1}$ ; D2(ref) is the duration between two adjacent quench exchanger decoking intervals, in days;  $\text{delta}D2 = D2 - D2(\text{ref})$ , where D2 is the duration between two adjacent quench exchanger decoking intervals, in days; P3 is average coke removed during the plurality of quench exchanger decoking intervals in mm; and P3(ref) is average coke removed during the plurality of reference quench exchanger decoking intervals in mm.

24. The process of claim 23, wherein  $-0.5 \text{ mm} \leq BB \leq 0.5 \text{ mm}$ .

25. The process of claim 22, wherein the decoking process conditions comprise at least one of: (i) introducing the decoking feed into the at least one of the radiant coils to produce a decoking effluent having a coil outlet temperature of  $>900^\circ \text{ C.}$ ; (ii) introducing the decoking feed into the at

least one of the radiant coils or into one or more quench exchanger inlets in fluid communication with the at least one of the radiant coils at a mass flux rate at the quench exchanger inlet of  $>39 \text{ kg} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ ; and (iii) introducing the decoking feed into the at least one of the radiant coils while maintaining introduction of the first hydrocarbon feed into one or more of the radiant coils in the plurality of radiant coils.

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