PROCESS AND APPARATUS FOR COOLING LIQUID BOTTOMS FROM VAPOR-LIQUID SEPARATOR BY HEAT EXCHANGE WITH FEEDSTOCK DURING STEAM CRACKING OF HYDROCARBON FEEDSTOCKS

FIELD OF THE INVENTION

[0001] The present invention relates to the cracking of hydrocarbon feedstocks, particularly those that contain relatively non-volatile hydrocarbons and other contaminants. In particular, the present invention relates to cooling hot liquid bottoms taken from a vapor-liquid separation apparatus used in steam cracking hydrocarbon feedstocks, while preheating a hydrocarbon feedstock to a pyrolysis furnace.

BACKGROUND OF THE INVENTION

[0002] Steam cracking, also referred to as pyrolysis, has long been used to crack various hydrocarbon feedstocks into olefins, preferably light olefins such as ethylene, propylene, and butenes. Conventional steam cracking utilizes a pyrolysis furnace which has two main sections: a convection section and a radiant section. The hydrocarbon feedstock typically enters the convection section of the furnace as a liquid (except for light feedstocks which enter as a vapor) wherein it is typically heated and vaporized by indirect contact with hot flue gas from the radiant section and by direct contact with steam. The vaporized feedstock and steam mixture is then introduced into the radiant section where the cracking takes place. The resulting products, including olefins, leave the pyrolysis furnace for further downstream processing, including quenching.

[0003] Conventional steam cracking systems have been effective for cracking high-quality feedstocks such as gas oil and naphtha. However, steam cracking economics sometimes favor cracking low cost heavy feedstock such as, by way of non-limiting examples, crude oil and atmospheric resid, also known as atmospheric pipestill bottoms. Crude oil and atmospheric resid contain high molecular weight, non-volatile components, e.g., asphaltenes, resid, and/or pitch, with boiling points in excess of 590° C (1100° F). The non-volatile, heavy ends of these feedstocks lay down as coke in the convection section of conventional pyrolysis furnaces. Only very low levels of non-volatiles, say, e.g., less than 50 ppmw, or even less than 5 ppmw can be tolerated in the convection section downstream of the point where the lighter components have fully vaporized. Additionally, some naphthas are contaminated with crude oil during transport. Conventional pyrolysis furnaces do not have the flexibility to process resids, e.g., atmospheric resids, crudes, or many resid- or

crude-contaminated gas oils or naphthas, which contain a large fraction of heavy non-volatile hydrocarbons, say, from 50 to 100000 ppmw.

[0004] In furnaces processing such feeds, the crude oil or resid is typically preheated and mixed with dilution steam, and only partially vaporized before it is removed from the convection section and fed to a vapor-liquid separator (flash drum or flash vessel) to separate heavy non-volatile hydrocarbons from lighter volatile hydrocarbons which are fed back to the convection section of the furnace for additional preheating and then cracked in the radiant section of the pyrolysis furnace. It is important to maximize non-volatile hydrocarbon removal efficiency in this process. Otherwise, heavy, coke-forming non-volatile hydrocarbons could be entrained in the vapor phase and carried overhead into the furnace creating coking problems in the convection section. The heated liquid bottoms produced from such flashing typically must be cooled, thereby providing an opportunity to enhance thermal efficiency of the overall steam cracking process.

[0005] U.S. Patent 3,617,493, which is incorporated herein by reference, discloses the use of an external vaporization drum for the crude oil feed and discloses the use of a first flash to remove naphtha as vapor and a second flash to remove vapors with a boiling point between 230° C and 590° C (450° F and 1100° F). The vapors are cracked in the pyrolysis furnace into olefins and the separated liquids from the two flash tanks are removed, stripped with steam, and used as fuel. U.S. Patents 7,097,758 and 7,138,047, both of which are incorporated by reference herein, disclose furnaces for processing high levels of non-volatile hydrocarbons (or resids) wherein the feedstocks are preheated, mixed with dilution steam and water, partially vaporized in the convection section and then fed to a vapor-liquid separator to remove non-volatiles as liquid, prior to cracking.

[0006] In order to achieve a stable commercial operation on a furnace employing an external vapor-liquid separator or flash drum, it is necessary to have a configuration and control system that can maintain a desired inlet temperature to the vapor-liquid separator. U.S. Patent 7,138,047, incorporated herein by reference, describes an advantageously controlled process to optimize the cracking of volatile hydrocarbons contained in the heavy hydrocarbon feedstocks and to reduce and avoid coking problems. It provides a method to maintain a relatively constant ratio of vapor to liquid leaving the flash by maintaining a relatively constant temperature of the stream entering the flash. More specifically, the constant temperature of the flash stream is maintained by automatically adjusting the amount of a fluid stream mixed with the heavy hydrocarbon feedstock prior to the flash. Thus, a

variable quantity of a dilution liquid (or fluid), preferably water, is substituted for dilution steam as required to keep the vapor-liquid separator (flash) temperature substantially constant, despite load changes that the furnace may experience. The bottoms from the flash can be cooled in a heat exchanger and exported or recycled to the flash drum.

[0007] At least the first stage of cooling can be achieved in a heat exchanger located in close proximity to the vapor-liquid separator. This heat exchanger has been used in the past to cool the liquid stream from the separator by generating medium pressure steam (693 to 1138 kPa (100 to 150 psig)) which can be exported to the plant medium pressure steam header.

[0008] U.S. Patent 7,351,872, incorporated herein by reference, teaches alternate ways of maintaining vapor-liquid separator temperature, e.g., by varying furnace draft, which can dispense with the need for water injection entirely.

[0009] U.S. Patent Application Ser. No. 12/132,130, filed June 3, 2008 discloses cooling liquid bottoms taken from a vapor-liquid separation apparatus used in steam cracking hydrocarbon feeds, by heat exchange with high pressure boiler feed water.

[0010] During flashing to separate heavy liquid hydrocarbon fractions containing resid from the lighter fractions which can be processed in the pyrolysis furnace, it would be desirable to cool the liquid bottoms fraction in such a way as to efficiently recover their heat. Accordingly, it would be desirable to provide a process for cooling liquid phase materials, e.g., bottoms, taken from a flash drum used to separate heavy liquid hydrocarbon fractions containing resid from the lighter fractions which can be processed in the pyrolysis furnace, while utilizing transferred heat to efficiently integrate the heat recovery in the overall furnace design.

SUMMARY OF THE INVENTION

[0011] In one aspect, the present invention relates to a process for cooling liquid bottoms from a vapor-liquid separator used in separating heated hydrocarbon feedstock that is to be cracked, which comprises: i) indirectly heat exchanging hot liquid bottoms, e.g., having a temperature ranging from 200° C to 500° C (392° F to 932° F), say, from 250° C to 350° C (482° F to 662° F), with a cool hydrocarbon feedstock, e.g., having a temperature ranging from 20° C to 200° C (68° F to 392° F), say, from 50° C to 150° C (122° F to 302° F), to provide cooled liquid bottoms, e.g., at a temperature ranging from 50° C to 350° C (122° F to 662° F), say, from 70° C to 300° C (158° F to 572° F), and preheated hydrocarbon feedstock,

e.g., at a temperature ranging from 50° C to 300° C (122° F to 572° F), say, from 70° C to 200° C (158° F to 392° F); and ii) directing at least a portion of the preheated hydrocarbon feedstock to a convection section inlet of a pyrolysis furnace comprising a) a convection section having at least one convection zone and b) a radiant section. Step ii)'s directing of the preheated hydrocarbon feedstock to the convection section inlet results in additional heating and subsequent cracking of the feedstock. The cool hydrocarbon feedstock can typically contain "resid," described further below. For present purposes, the term "hot liquid bottoms" can be defined as a liquid bottoms stream of sufficient heat content for transfer to a cooler stream using an indirect heat exchanger. Similarly, the term "cool hydrocarbon feedstock" can be defined as a hydrocarbon feedstock stream which is sufficiently cool to accept heat transferred from a hotter stream using an indirect heat exchanger. Typically, the temperature difference between the hot liquid bottoms and the cool hydrocarbon feedstock can be at least 25° C (77° F), say, at least 100° C (212° F), e.g., at least 200° C (392° F).

[0012] In certain embodiments, the process of the invention further comprises: iii) introducing diluent steam to the preheated hydrocarbon feedstock; and, optionally, iv) introducing a liquid diluent to the preheated hydrocarbon feedstock. The introduced liquid diluent, typically comprising water, can be reduced as a function of the extent to which the hydrocarbon feedstock is preheated. The introduced liquid diluent can be substituted for the steam diluent in an amount sufficient to maintain a substantially constant temperature in the vapor-liquid separator. In an embodiment of the process, the hydrocarbon feedstock can vary from heavier feedstocks selected from heavy crude oil and atmospheric resid, to lighter feedstocks selected from lighter crude oils and mixtures of crude oil and condensate.

[0013] In another aspect, the present invention relates to a process for cracking a hydrocarbon feedstock in a pyrolysis furnace comprising at least one convection section and a radiant section, the process comprising: (a) introducing a preheated hydrocarbon feedstock, for further heating in a convection zone, such as but not limited to an upper convection zone; (b) mixing the preheated hydrocarbon feedstock with dilution steam and, optionally, a dilution liquid, e.g., water, to form a mixture stream; (c) separating the mixture stream in a vapor-liquid separator to form I) a vapor phase and II) a liquid phase; (d) removing the vapor phase as overhead and the liquid phase as bottoms from the vapor-liquid separator; (e) cooling the hotter bottoms in a heat exchanger outside the pyrolysis furnace by indirect heat exchange with a cooler hydrocarbon feedstock to provide at least a portion of the preheated hydrocarbon feedstock; (f) cracking the vapor phase in the radiant section of a pyrolysis

furnace to produce an effluent comprising olefins; and (g) recovering cracked product from the effluent comprising olefins.

[0014] In one embodiment of this aspect of the invention, the mixture stream is heated in an additional convection zone prior to its introduction to the vapor-liquid separator.

[0015] In another embodiment of this aspect, the vapor phase is heated in an additional convection zone prior to cracking.

[0016] In still another embodiment of this aspect, the at least one convection zone comprises a tube bank heat exchanger.

[0017] In yet another embodiment of this aspect of the invention, the process further comprises quenching the effluent comprising olefins from cracking, prior to recovering cracked product.

[0018] In still yet another embodiment of this aspect, the process further comprises recycling a portion of the cooled liquid bottoms to the vapor-liquid separator.

[0019] In certain embodiments of this aspect of the present invention, the process can further comprise at least one of: (h) heat exchanging high pressure boiler feed water with hot flue gas in a convection zone to provide preheated high pressure boiler feed water; (i) heat exchanging dilution steam with hot flue gas in a convection zone to provide heated dilution steam; (j) optionally adding desuperheater water to the heated dilution steam, providing a cooled mixture; (k) adding the heated dilution steam and optional desuperheater water to the mixture stream of (b); (l) heat exchanging superheated high pressure steam with hot flue gas in a convection zone to provide heated superheated high pressure steam; (m) adding desuperheater water to the heated superheated high pressure steam to provide a stream of superheated high pressure steam at reduced temperature; and (n) heat exchanging the stream of (m) with hot flue gas in a convection zone to provide superheated high pressure steam at a temperature suitable for export to a header. Such temperature can be at least 370° C (700° F), typically ranging from 477° C to 565° C (890° F to 1050° F). For present purposes, temperatures for a specific stream to be heated or cooled can be measured at the appropriate inlet or outlet of the heat exchange means from which they are received or taken, unless otherwise described.

[0020] In an embodiment of this aspect of the invention, the liquid bottoms from the vapor-liquid separation apparatus range from 250° C to 350° C (482° F to 662° F), the cooled liquid bottoms range from 90° C to 260° C (194° F to 500° F), the hydrocarbon feedstock

ranges from 70° C to 150° C (158° F to 302° F), and the preheated hydrocarbon feedstock ranges from 90° C to 200° C (194° F to 392° F).

[0021] In another embodiment of this aspect of the invention, the dilution liquid used to form the mixture stream of (b) is reduced as a function of the extent to which the hydrocarbon feedstock is preheated.

[0022] In still another embodiment of this aspect of the invention, the dilution liquid is substituted for the dilution steam in an amount sufficient to maintain a substantially constant temperature in the vapor-liquid separator.

[0023] In yet another embodiment of this aspect of the invention, the hydrocarbon feedstock is selected or varied over a range of hydrocarbon liquid feeds, from heavier feedstocks to lighter feedstocks. For present purposes the heavier feedstocks comprise higher boiling fractions than lighter feedstocks. Heavier feedstocks can be selected, for example, from heavy crude oil and atmospheric resid, while lighter feedstocks can be selected, for example, from lighter crude oils and mixtures of crude oil and condensate.

[0024] In still another aspect, the present invention relates to an apparatus for cracking a preheated hydrocarbon feedstock in a pyrolysis furnace comprising a) a convection section having at least one convection zone, and b) a radiant section, the apparatus comprising: (1) an inlet for receiving preheated hydrocarbon feedstock; (2) a convection zone for heating the preheated hydrocarbon feedstock; (3) at least one inlet for introducing steam, or steam and water, to the heated hydrocarbon feedstock to form a mixture stream; (4) a vapor-liquid separator, which can be external to the pyrolysis furnace, for treating the mixture stream to form I) a vapor phase and II) a liquid phase, the separator further comprising an overhead outlet for substantially removing the vapor phase as overhead and a liquid outlet for substantially removing the liquid phase as heated bottoms from the vapor-liquid separator; (5) a heat exchanger, external to the pyrolysis furnace, for cooling the vapor-liquid separator bottoms by indirect heat exchange, comprising an inlet for receiving heated bottoms from the separator, an outlet for withdrawing cooled bottoms, an inlet for receiving cool hydrocarbon feedstock as a heat exchange medium to the heat exchanger, and an outlet for withdrawing preheated hydrocarbon feedstock; (6) a line for directing at least a portion of the withdrawn preheated hydrocarbon feedstock to the inlet for receiving preheated hydrocarbon feedstock; and (7) a radiant section for cracking the heated vapor phase to produce an effluent comprising olefins.

[0025] In certain embodiments of this aspect of the invention, the apparatus can further comprise at least one of: (8) a convection zone for heating the mixture stream; (9) a convection zone for heating the overhead to provide a heated vapor phase; (10) a quench exchanger for cooling the effluent comprising olefins; and (11) a recovery train for recovering light olefins from the effluent comprising olefins.

[0026] In an embodiment of this aspect of the invention, the at least one convection zone comprises at least one heat exchanger tube bank.

[0027] In still other embodiments of this aspect of the invention, the apparatus further comprises at least one of: (12) a heat exchanger for preheating high pressure boiler feed water with hot flue gas in a convection zone to provide preheated high pressure boiler feed water; (13) a heat exchanger for heating dilution steam with hot flue gas in a convection zone to provide heated dilution steam; (14) an inlet for adding desuperheater water to the heated dilution steam; (15) an inlet for adding the heated dilution steam to the mixture stream of (3); (16) an inlet for adding desuperheater water to the mixture stream of (3); (17) a heat exchanger for superheating high pressure steam with hot flue gas in a convection zone to provide heated superheated high pressure steam; (18) an inlet for adding desuperheater water to the heated superheated high pressure steam to provide a stream of superheated high pressure steam at reduced temperature; and (19) a heat exchanger for heating the mixture of heated superheated high pressure steam and desuperheater water with hot flue gas in a convection zone to provide superheated high pressure steam at a temperature suitable for export to a header.

BRIEF DESCRIPTION OF THE DRAWING

[0028] The FIGURE illustrates a schematic flow diagram of the overall process and apparatus in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0029] The present invention provides an efficient way of treating the liquid bottoms from a vapor-liquid separation apparatus, which are associated with a hydrocarbon pyrolysis reactor used for steam cracking. The invention provides efficient removal and recovery of heat from the bottoms stream by preheating a hydrocarbonaceous feed to the reactor. The hydrocarbon pyrolysis reactor (or furnace) used in the present invention comprises a convection section having at least one convection zone, and a radiant section. For present purposes, a convection section can be described as that portion of the furnace wherein a

feedstock is treated by convection heating, e.g., by indirect heat exchange of hot flue gas from the radiant section, in passages having heat conducting surfaces, e.g., a bank of metal tubes. The convection section typically comprises one or more convection zones, each zone having an inlet to and an outlet from the convection section. A convection section can typically comprise one or more heating zones, as well as a preheating zone, although the latter can be redundant in the present invention which preheats feedstock in a heat exchanger utilizing heated bottoms from a vapor-liquid separator. Each convection zone is typically associated with a specific tube bank for effecting heat exchange. In an embodiment of the invention, an internal or external vapor-liquid separator, e.g., flash drum or vessel, can be interposed between convection zones. The convection section may also include separate convection zones which treat other streams, e.g., boiler feed water, steam, etc.

[0030] For present purposes, unless otherwise described, conditions, e.g., temperatures, of a reactant stream or starting material stream are measured at the inlet of the zone in which they are treated, while conditions for a treated stream are typically measured at the outlet of the zone in which they are treated. The heat exchanger used to cool the hot liquid bottoms can be any suitable heat exchanger means, e.g., a shell-and-tube exchanger, spiral wound exchanger, airfin, or double-pipe exchanger.

[0031] The present invention is used in the steam cracking of hydrocarbon feedstocks, especially liquid hydrocarbon feedstocks, e.g., those having a nominal final boiling point of at least 315° C (600° F). These feedstocks typically contain non-volatile components.

[0032] As used herein, non-volatile components, or resids, are the fraction of the hydrocarbon feed with a nominal boiling point above 590° C (1100° F) as measured by ASTM D-6352-98 or D-2887. This invention works very well with non-volatiles having a nominal boiling point above 760° C (1400° F). The boiling point distribution of the hydrocarbon feed is measured by Gas Chromatograph Distillation (GCD), also measured by ASTM D-6352-98 or D-2887. Non-volatiles include coke precursors, which are large, condensable molecules that condense in the vapor, and then form coke under the operating conditions encountered in the present process of the invention.

[0033] Typical hydrocarbon feedstocks suited to use for steam cracking in the present invention are commonly selected from the exemplary group including steam cracked gas oil/residue admixtures, gas oils, heating oil, jet fuel, diesel, kerosene, gasoline, coker naphtha, steam cracked naphtha, catalytically cracked naphtha, hydrocrackate, reformate, raffinate reformate, Fischer-Tropsch liquids, Fischer-Tropsch gases, natural gasoline,

distillate, virgin naphtha, crude oil, atmospheric pipestill bottoms, vacuum pipestill streams including bottoms, wide boiling range naphtha to gas oil condensates, heavy non-virgin hydrocarbon streams from refineries, vacuum gas oils, heavy gas oil, naphtha contaminated with crude, atmospheric residue, heavy residue, hydrocarbon gas/residue admixtures, hydrogen/residue admixtures, C_4's/residue admixtures, naphtha/residue admixtures and gas oil/residue admixtures, and mixtures thereof.

[0034] In order to achieve stable commercial operation in a pyrolysis furnace which utilizes a vapor-liquid separator, it has been found desirable to have a furnace configuration and control system that can maintain the desired inlet temperature to the vapor-liquid separator. As earlier noted, U.S. Patent 7,138,047 describes a system where a variable quantity of a dilution fluid, preferably water, is substituted for dilution steam as needed to keep the vapor-liquid separator temperature constant, despite load changes experienced by the furnace.

[0035] For heavy crude oils or atmospheric resids, it is usually desired to operate the vapor-liquid separator at the highest possible temperature in order to maximize the quantity of the feed that is recovered to the radiant section of the pyrolysis furnace for cracking to light olefins. Such target temperatures generally fall between 400° C and 500° C (752° F and 932° F). The upper limit is typically set by the onset of thermal cracking and fouling in the overhead lines from the vapor-liquid separator, e.g., temperatures of 460° C (860° F). For lighter feeds, e.g., lighter crude oils, or mixtures of crude oil and condensate, the concentration of non-volatile hydrocarbons in the separator bottoms liquid may reach a maximum value prior to the separator temperature reaching the aforesaid upper limit. In such instances, it is desirable to operate the separator at a lower temperature to maintain an adequate quantity and quality of the separator bottoms liquid. Such temperatures depend on the boiling range of the feed mixture, and can range from 400° C to 450° C (752° F to 842° F).

[0036] The liquid bottoms stream from the vapor-liquid separator is cooled prior to being sent to storage or alternative downstream disposition. At least the first stage of cooling can be achieved in a heat exchanger in proximity to the vapor-liquid separator.

[0037] The pyrolysis furnace of U.S. Patent 7,138,047, suitable for use in the present invention, utilizes a mixture of steam and fluid, e.g., water, as diluent, and can be operated in a commercially stable operation on a wide variety of feedstocks containing non-volatile hydrocarbons. However, its operation is most efficient when process feedstocks require a

high vapor-liquid separator temperature. In such cases, the rate of water injection into the convection section can be minimized. Additional control techniques for a pyrolysis furnace described in U.S. Patent 7,351,872, incorporated herein by reference in its entirety, include adjusting furnace draft to control the inlet temperature of the vapor-liquid separator, and can eliminate the need for water injection where feed quality remains consistent. However, if the furnace must process not only feedstocks requiring a high separator temperature, e.g., whole crude or atmospheric resid, but feedstocks requiring low separator temperature, e.g., crude oil/condensate mixture, significant quantities of water must be substituted for dilution steam to maintain the separator at the required lower temperature.

[0038] Using such high water injection rates wastes valuable energy in the flue gas of the furnace being used to vaporize water, effectively using flue gas to generate dilution steam, rather than for a higher value heat recovery service. For example, the flue gas could otherwise be used to preheat high pressure boiler feed water, to increase super high pressure steam generation for a transfer line exchanger-equipped furnace. Thus, the use of significant amounts of water to reduce separator temperature reduces overall energy efficiency of the furnace.

[0039] Moreover, each mass of water injected into the convection section of a furnace in place of dilution steam requires an incremental mass of sour condensate blowdown from the dilution steam generation system. This increases both the cost of the waste water treatment facilities required by the plant in question, and also increases the volume of the treated water discharge from the plant.

[0040] In contrast, the present invention provides for using a broad range of feedstocks containing non-volatile hydrocarbons to be processed across a reasonable range of vapor-liquid separator temperatures, without requiring injection of significant volumes of water in place of dilution steam in the convection section of the furnace.

[0041] Generally, heavy crude oil feedstocks that require high convection section heat input to achieve the desired separator temperatures tend to produce copious amounts of separator bottoms and so have commensurately high liquid flow rates leading from the separator bottoms. In contrast, lighter feedstocks such as crude oil/condensate mixtures that require lower separator temperatures tend to have low liquid flow rates leading from the separator bottoms.

[0042] Surprisingly, it has been found that the need for water injection in place of dilution steam in the convection section can be minimized if, instead of accomplishing all the feed preheat duty in the furnace convection section, the feed is first preheated against separator bottoms in a heat exchanger, and the preheated feed is then fed to a convection section of the pyrolysis furnace. The invention is particularly advantageous because the present invention balances the high preheat duty required of heavy feedstocks with the heat provided by heat exchange of the high liquid flow rates of separator bottoms associated with the processing of heavier feeds. Similarly, the reduced preheat duty required by lighter feedstocks is balanced by the heat exchange with the low liquid flow rates from the separator bottoms that are associated with lighter feedstocks. This permits efficient and substantially self-regulating energy recovery from the flue gas with minimal water injection into the convection section for both the heavy feedstocks and the light feedstocks.

[0043] The balancing of convection section duties and separator temperatures may also be aided by varying the temperature at which the feed is supplied to the preheat exchanger. For applications requiring high preheat duties, e.g., heavy crude oils, higher supply temperatures are favored. For low preheat duties, e.g., crude oil/condensate mixtures, low supply temperatures are favored. This balancing can further be aided by varying the excess O_2 levels at which the furnace is operated. For applications requiring high preheat duties, higher excess O_2 levels are desirable, for lower preheat duties, lower excess O_2 levels are preferred.

[0044] In applying this invention, the hydrocarbon feedstock, which typically contains resid, is preheated outside the pyrolysis furnace comprising a convection section with one or more convection zones, and a radiant section, prior to introduction of the hydrocarbon feedstock to the convection zone for initially heating feedstock within the convection section of the pyrolysis furnace. The preheating can be carried out by heat exchanging the hydrocarbon feedstock with a suitable source of heat. In particular, the present invention utilizes as the heat source a hot liquid bottoms stream taken from a vapor-liquid separator that is located downstream of the initial convection zone for heating feedstock in the convection section of the pyrolysis furnace, and upstream of the radiant section of the pyrolysis furnace. The preheated hydrocarbon feedstock can be further heated by indirect contact with flue gas in a convection zone tube bank of the pyrolysis furnace before mixing with a fluid, e.g., steam, and optionally, liquid water. Preferably, the temperature of the

hydrocarbon feedstock is from 130° C to 260° C (266° F to 500° F), before mixing with the fluid.

[0045] Following mixing with the primary dilution steam stream and optional liquid water, the mixture stream may be heated by indirect contact with flue gas in the convection section of the pyrolysis furnace before being flashed. Preferably, the convection section is arranged to add the primary dilution steam stream and any liquid water, between convection zones such that the hydrocarbon feedstock can be heated before mixing with the fluid and the mixture stream can be further heated before being flashed.

[0046] The temperature of the flue gas entering the uppermost (or furthest upstream) convection zone tube bank for heating feedstock is generally less than 815° C (1500° F), for example, less than 705° C (1300° F), such as less than 620° C (1150° F), and preferably less than 540° C (1000° F).

[0047] Dilution steam may be added at any point in the process, for example, it may be added to the hydrocarbon feedstock before or after heating, to the mixture stream, and/or to the vapor phase. Any dilution steam stream may comprise sour steam. Any dilution steam stream may be heated or superheated in a convection zone tube bank located anywhere within the convection section of the furnace.

[0048] The mixture stream may be at 315° C to 540° C (600° F to 1000° F) before introduction to the vapor-liquid separator or flash apparatus, e.g., knockout drum, and the flash pressure may be 275 to 1375 kPa (40 to 200 psia). Following the flash, 50 to 98% of the mixture stream may be in the vapor phase. An additional separator such as a centrifugal separator may optionally be used to remove trace amounts of liquid from the vapor phase. The vapor phase may be heated to above the flash temperature before entering the radiant section of the furnace, for example, to 425° C to 705° C (800° F to 1300° F). This heating may occur in a convection section tube bank, preferably the tube bank in the convection zone nearest the radiant section of the furnace.

[0049] A transfer line exchanger can be used to produce high pressure steam which is then preferably superheated in a convection section tube bank of the pyrolysis furnace, typically to a temperature less than 590° C (1100° F), for example, 370° C to 565° C (700° F to 1050° F) by indirect contact with the flue gas before the flue gas enters the convection section tube bank used for heating the heavy hydrocarbon feedstock and/or mixture stream. An intermediate desuperheater may be used to control the temperature of the high pressure

steam. The high pressure steam is preferably at a pressure of 4240 kPa (615 psia) or greater and may have a pressure of 10450 to 13900 kPa (1515 to 2015 psia). The high pressure steam superheater tube bank is preferably located in a convection zone between the first convection zone tube bank and the convection zone tube bank used for heating the vapor phase.

[0050] The cooled gaseous effluent derived from the transfer line exchanger is directed to a recovery train for recovering C_2 to C_4 olefins, inter alia.

[0051] The invention will now be more particularly described with reference to the example shown in the accompanying drawing. Operating conditions within the process shown in the drawing are provided in TABLE 1.

[0052] Referring to the FIGURE, a hydrocarbon feedstock **10**, e.g., heavy crude oil requiring high preheat duties, or crude oil/condensate mixtures requiring low preheat duties, is preheated by passing through heat exchanger **12**. The initial feed temperature is measured at the heat exchanger inlet, and the feed temperature exiting the heat exchanger, is measured at the heat exchanger outlet. Preheated feed passes via line **14** into a first convection zone exchanger tube bank **15** in steam cracking furnace (pyrolysis reactor) **16** at the upper portion of convection section **18** for additional preheating. Heating of the feedstock within the convection section is by indirect contact of the feedstock in the convection section of the furnace, using hot flue gases from the radiant section **20** of the furnace exiting via furnace outlet **22** which can be associated with a blower **23** to vary draft as needed. After the additional preheating, the feedstock as measured at the outlet of the first convection zone exchanger tube bank in the upper convection section has a temperature between 100° C and 300° C (212° F and 572° F). Preferably, the temperature of the heated feedstock is between 120° C and 270° C (248° F and 518° F), and most preferably between 130° C and 250° C (266° F and 482° F). The additionally preheated feedstock passes through a sparger **24** that receives water via line **26** controlled by valve **28** to introduce water or other suitable fluid to the feed. Dilution steam is introduced to the sparger via line **30** controlled by valve **32** where it mixes with the feedstock and water, the mixture exiting the sparger via line **34** which returns to an intermediate convection zone tube exchanger bank **35** for additional heating of the mixture which is taken outside the convection section via line **36** for reintroduction to the convection section for further heating in a lower intermediate convection zone tube bank. The mixture again exits the convection section, this time via line **38** to a vapor-liquid

separator **40** through a side inlet **42**. Liquid is taken as bottoms from the separator via bottom outlet **44** (at which point bottoms temperatures can be measured) via line **46** and then directed via pump **48** as heat transfer medium to heat exchanger **12**. The liquid separator bottoms taken from the heat exchanger can be recycled via line **50**, controlled by valve **52** to the boot **54** of the vapor-liquid separator. Unrecycled liquid bottoms are collected for liquid stream export via line **56** controlled by valve **58**. Superheated dilution steam can be mixed with the feed to the vapor-liquid separator via line **64**, intermediate convection zone tube exchanger bank **68**, and line **70**, controlled by valve **66**. Desuperheating water can be mixed with the superheated dilution steam via line **60** controlled by valve **62**. The heated dilution steam passes via line **70** to the vapor-liquid separator via line **38**. Normally, the desuperheater maintains the temperature of the dilution steam between 425° C and 590° C (800° F and 1100° F), for example, between 455° C and 540° C (850° F and 1000° F), such as between 455° C and 510° C (850° F and 950° F), and typically between 470° C and 495° C (875° F and 925° F), as measured at the inlet to the vapor-liquid separator **40**. The desuperheater can be a control valve and water atomizer nozzle.

[0053] The vapor from the vapor-liquid separator **40** passes as overhead via line **72** to a downstream convection zone tube exchanger bank **79** where it is heated, and thence to crossover line **76** from which it is directed to the radiant section **20** from which it emerges as hot gaseous pyrolysis effluent.

[0054] The hot gaseous pyrolysis effluent exits the radiant section **20** of steam cracking furnace **16** via line **78** into at least one primary transfer line heat exchanger **80** that cools the effluent from an inlet temperature ranging from 704° C to 927° C (1300° F and 1700° F), say, from 760° C to 871° C (1400° F to 1600° F), e.g., 816° C (1500° F), to an outlet temperature ranging from 316° C to 704° C (600° C to 1300° F), say, from 371° C to 649° C (700° F to 1200° F), e.g., 538° C (1000° F). The outlet temperature of this exchanger rises rapidly from 443° C to 527° C (830° F to 980° F), and then more slowly to 549° C (1020° F). The effluent from the transfer line exchanger can then be directed by line **82** to further treatment, e.g., quenching and further processing by a recovery train to provide separate fractions of light olefins.

[0055] High pressure boiler feed water can be directed via line **84** for preheating to a high pressure boiler feed water heat exchange coil **86** located below the intermediate convection zone tube exchanger bank coil **35** that receives sparger **24** effluent via line **34**. The preheated

high pressure boiler feed water is directed to a steam drum (not shown) via line **88**. Alternate or additional heating of high pressure boiler feed water can be carried out by directing a source of high pressure boiler feed water **90** to a low temperature high pressure boiler feed water preheat coil **92** situated above the initial feed inlet to the furnace at the first convection zone heat exchanger tube bank **15**. This preheated boiler feed water can be directed via line **94** to the high pressure boiler feed water heat exchange coil **86** for additional preheating as necessary. The use of the low temperature high pressure boiler feed water preheat coil **92** heat provides for efficient furnace operation for a wider variety of feed cases using heat from flue gas that would otherwise be vented to the atmosphere.

[0056] Saturated high pressure steam is taken from a steam drum via line **96** to a high pressure steam heat exchange coil **98** located in a convection zone beneath high pressure boiler feed water heat exchange coil **86**. The heated superheated high pressure steam is directed outside the convection section **18** via line **100** where desuperheater water can be added to the heated superheated high pressure steam via line **102** controlled by valve **104**. The heated superheated high pressure steam having a pressure of at least 4100 kPa (600 psia) (or resulting mixture of steam and water) can be directed via line **100** for additional heating to a convection zone for secondary superheated high pressure steam heater **106** located below the lower intermediate convection zone tube bank **37** for heating. The resulting heated superheated high pressure steam is exported from the pyrolysis furnace via line **108**.

[0057] TABLE 1 below illustrates the predicted performance of a furnace having the convection zones, vapor-liquid separator, and feed preheater/bottoms cooler arrangement shown in the FIGURE described above. The predicted performance is based upon a computer simulation.

TABLE 1

Feed	Heavy Crude Oil		Crude Oil		Crude Oil/Condensate	
Furnace Condition	Start of Run	End of Run	Start of Run	End of Run	Start of Run	End of Run
Feed Rate (tons/h)	121	121	112	112	93	93
Feed Temp to Feed Preheater (°C)	132	132	93	93	73	73
Water Rate (tons/h)	0	0	0	0	0	4
Separator Inlet T (°C)	455	455	460	460	447	447
% Feed to Radiant Section	74	74	91	91	95	95
Furnace Firing (Megawatts)	142	144	156	158	138	144
Furnace Excess O_2 (wet vol.%)	4.5	3.5	3.1	2.0	2.7	2.0
Flue Gas T above Feed inlet (°C)	231	227	178	176	141	136
Preheated Feed T to Convection Sec. (°C)	198	198	118	118	87	87
Separator Bottoms T to Preheater (°C)	344	344	316	316	268	268
Bottoms T to Export (°C)	254	254	200	200	235	235
Bottoms Export Rate tons/h	34.6	34.6	10.1	10.1	4.6	4.6
Bottoms Cooler/Feed Preheater Duty (Megawatts)	5.1	5.1	1.7	1.7	1.3	1.3

[0058] As can be shown from the data in TABLE 1, as the feed becomes lighter, the duty transferred to the feed by the vapor-liquid separator bottoms heat exchanger or cooler is reduced, permitting operation with a wide variety of feeds. Water injection is necessary (and only to a minor extent) in the case of the lightest feeds. Thus, the present invention provides for a wide range of hydrocarbonaceous feedstocks to be processed, such as crude oils and atmospheric resids, while minimizing the flow rate of water to the convection section, thereby reducing the energy inefficiencies and environmental treatment demands associated with the addition of fluids such as water to the steam cracking process.

[0059] While the invention has been described in connection with certain preferred embodiments so that aspects thereof may be more fully understood and appreciated, it is not intended to limit the invention to these particular embodiments. On the contrary, it is

intended to cover all alternatives, modifications and equivalents as may be included within the scope of the invention as defined by the appended claims.

CLAIMS

What is claimed is:

1. A process for cooling liquid bottoms from a vapor-liquid separator used in separating heated hydrocarbon feedstock that is to be cracked, which comprises:

i) indirectly heat exchanging hot liquid bottoms with a cool hydrocarbon feedstock to provide cooled liquid bottoms and preheated hydrocarbon feedstock;

ii) directing at least a portion of the preheated hydrocarbon feedstock to a convection section inlet of a pyrolysis furnace comprising a) a convection section having at least one convection zone, and b) a radiant section; and

iii) utilizing the indirect heat exchanging for regulating the preheated hydrocarbon feedstock's temperature upstream of the vapor-liquid separator (i) without added liquid diluent or (ii) with a minimum amount of added liquid diluent.

2. The process of claim 1 wherein the hot liquid bottoms range from 200°C to 500°C, the cool hydrocarbon feedstock contains resid and ranges from 20°C to 200°C, the cooled liquid bottoms range from 50°C to 350°C, and the preheated hydrocarbon feedstock ranges from 50°C to 300°C.

3. The process of claim 1 which further comprises:

iii) introducing diluent steam to the preheated hydrocarbon feedstock.

4. The process of any of claims 1- 3 wherein the introduced liquid diluent comprises water.

5. The process of claim 4 wherein the preheated hydrocarbon feedstock's temperature is regulated by adding a minimum amount of liquid diluent upstream of the vapor-liquid separator to maintain the preheated hydrocarbon feedstock at a substantially constant temperature in the vapor-liquid separator.

6. The process of claim 1, further comprising a process for cracking a hydrocarbon feedstock that includes a nominal final boiling point of at least 315°C, in a pyrolysis furnace comprising a convection section having at least one convection zone, and a

radiant section, the process comprising:

(a) introducing a preheated hydrocarbon feedstock for further heating in a convection zone;

(b) mixing the preheated hydrocarbon feedstock with dilution steam and, optionally, a dilution liquid to form a mixture stream;

(c) separating the mixture stream in a vapor-liquid separator to form I) a vapor phase and II) a liquid phase, relative to the heated mixture stream;

(d) removing the vapor phase as overhead and the liquid phase as hot bottoms from the vapor-liquid separator;

(e) cooling the hot bottoms in a heat exchanger outside the pyrolysis furnace by indirect heat exchange with a hydrocarbon feedstock to provide at least a portion of the preheated hydrocarbon feedstock in order to regulate the preheated hydrocarbon feedstock's temperature upstream of the vapor-liquid separator;

(f) cracking the vapor phase in the radiant section of a pyrolysis furnace to produce an effluent comprising olefins; and

(g) recovering cracked product from the effluent comprising olefins.

7. The process of claim 6 wherein the mixture stream is heated in an additional convection zone prior to its introduction to the vapor-liquid separator.

8. The process of claim 6 wherein the vapor phase is heated in an additional convection zone prior to cracking.

9. The process of claim 6 which further comprises recycling a portion of the cooled liquid bottoms to the vapor-liquid separator.

10. The process of claim 6 which further comprises at least one of:

(h) heat exchanging high pressure boiler feed water with hot flue gas in a convection zone to provide preheated high pressure boiler feed water;

(i) heat exchanging dilution steam with hot flue gas in a convection zone to provide heated dilution steam;

(j) optionally adding desuperheater water to the heated dilution steam;

(k) adding the heated dilution steam and optional desuperheater water to the

mixture stream of (b);

(l) heat exchanging superheated high pressure steam with hot flue gas in the convection section to provide heated superheated high pressure steam;

(m) adding desuperheater water to the heated superheated high pressure steam to provide a stream of superheated high pressure steam at reduced temperature; and

(n) heat exchanging the stream of (m) with hot flue gas in a convection zone to provide superheated high pressure steam at a temperature suitable for export to a header.

11. The process according to any of the preceding claims wherein the liquid bottoms from the vapor-liquid separation apparatus range from 250° C to 350° C, the cooled liquid bottoms range from 90° C to 260° C, the hydrocarbon feedstock ranges from 70° C to 150° C, and the preheated hydrocarbon feedstock ranges from 90° C to 200° C.

12. The process according to any of the preceding claims wherein the dilution liquid is substituted for the dilution steam in an amount sufficient to maintain a substantially constant temperature in the vapor-liquid separator.

13. An apparatus for cracking a preheated hydrocarbon feedstock in a process according to any of the preceding claims comprising a) a convection section having at least one convection zone and b) a radiant section, the apparatus comprising:

(1) an inlet for receiving preheated hydrocarbon feedstock;

(2) a convection zone for heating the preheated hydrocarbon feedstock;

(3) at least one inlet for introducing steam, or steam and water, to the heated hydrocarbon feedstock to form a mixture stream;

(4) a vapor-liquid separator for treating the mixture stream to form I) a vapor phase and II) a liquid phase, the separator further comprising an overhead outlet for substantially removing the vapor phase as overhead and a liquid outlet for substantially removing the liquid phase as heated bottoms from the vapor-liquid separator;

(5) a heat exchanger, external to the pyrolysis furnace, for cooling the vapor-liquid separator bottoms and regulating the heated hydrocarbon feedstock's temperature upstream of the vapor-liquid separator by indirect heat exchange, comprising an inlet for receiving heated bottoms from the separator, an outlet for withdrawing cooled bottoms,

an inlet for receiving cool hydrocarbon feedstock as a heat exchange medium to the heat exchanger, and an outlet for withdrawing preheated hydrocarbon feedstock;

(6) a line for directing at least a portion of the withdrawn preheated hydrocarbon feedstock to the inlet for receiving preheated hydrocarbon feedstock; and

(7) a radiant section for cracking the heated vapor phase to produce an effluent comprising olefins.

14. The apparatus of claim 13 which further comprises at least one of:

(8) a convection zone for heating the mixture stream;

(9) a convection zone for heating the overhead to provide a heated vapor phase;

(10) a quench exchanger for cooling the effluent comprising olefins; and

(11) a recovery train for recovering light olefins from the effluent comprising olefins.

15. The apparatus of claim 13 which further comprises at least one of:

(12) a heat exchanger for preheating high pressure boiler feed water with hot flue gas in a convection zone to provide preheated high pressure boiler feed water;

(13) a heat exchanger for heating dilution steam with hot flue gas in a convection zone to provide heated dilution steam;

(14) an inlet for adding desuperheater water to the heated dilution steam;

(15) an inlet for adding the heated dilution steam to the mixture stream of (3);

(16) an inlet for adding desuperheater water to the mixture stream of (3);

(17) a heat exchanger for superheating high pressure steam with hot flue gas in a convection zone to provide heated superheated high pressure steam;

(18) an inlet for adding desuperheater water to the heated superheated high pressure steam to provide a stream of superheated high pressure steam at reduced temperature; and

(19) a heat exchanger for heating the mixture of heated superheated high pressure steam and desuperheater water with hot flue gas in a convection zone to provide superheated high pressure steam at a temperature suitable for export to a header.