

**METHOD AND APPARATUS FOR STRIPPING NOX, OXYGEN, NITROGEN, CO,
AND CO₂ FROM FCC REGENERATED CATALYST FOR IMPROVING THE
PERFORMANCE, SAFETY, AND RELIABILITY OF PRODUCT RECOVERY
SECTION**

FIELD OF THE DISCLOSURE

[0001] Embodiments of the present disclosure generally relate to processes and systems to reduce flue gas components such as nitrogen oxides, sulfur oxides, oxygen, carbon monoxide, and carbon dioxide including nitrogen from FCC regenerated catalysts flowing from a catalyst regenerator to a riser-reactor.

BACKGROUND

[0002] In recent years, the changing dynamics of the market have prompted refineries to explore new opportunities in petrochemical production from crude oil, shifting their focus beyond fuel production as fuel demand is depleting. Among the key building blocks for the petrochemical industry, ethylene and propylene hold significant importance. Due to the depleting demand of fuels and increasing demand of petrochemicals, refiners are being compelled to find the options to maximize petrochemicals from processing a variety of crude oils. Ethylene and propylene are expected to be in high demand, as they are the primary feed stock for the petrochemical/polymer industries.

[0003] It has been proposed to directly process crude oils, or select boiling range fractions therefrom, without significant upstream processing, such as in a fluid catalytic cracking unit. Unfortunately, limiting upstream processing may result in a greater concentration of various impurities, such as sulfur and nitrogen, being introduced into the fluid catalytic cracking unit and associated downstream equipment.

SUMMARY OF THE CLAIMED EMBODIMENTS

[0004] In one aspect, embodiments disclosed herein relate to a method and apparatus for reducing the flue gas components, such as sulfur oxides, carbon oxides, nitrogen oxides, and oxygen, within a fluidized catalytic cracking (FCC) unit. The reduction of these flue gas components provides for safe and reliable operation of the downstream product recovery section. In particular, the NO_x contributes to gum formation, which maybe a safety hazard in the cold box section. This is achieved with the addition of

internals in the traditional Regenerated Catalyst Standpipe Hopper (RCSP Hopper) which will enable the efficient stripping of these harmful components of flue gas to the FCC reactor and product recovery section. The preferred stripping medium may be steam or other industrial inert gases such as nitrogen as compared to conventional fluffing media (plant air or blower air).

[0005] In another aspect, embodiments disclosed herein relate to a reduction in size of oxygen converter and catalyst due to reduction in flue gas components. This will also reduce the loss of ethylene product across the oxygen converter.

[0006] In another aspect, embodiments disclosed herein relate to a to reduction of other flue gas components like sulfur oxides, carbon monoxides, carbon dioxides etc.; which are the combustion products of the feed impurities landing into FCC regenerator with same claimed scheme. This will help in reducing the size of down product recovery section and will also reduce the utility consumption.

[0007] Embodiments herein thus relate to a process for cracking hydrocarbons. The process includes contacting a hydrocarbon feedstock with a conditioned cracking catalyst in a riser reactor to recover a riser effluent comprising spent catalyst and cracked hydrocarbons. The riser effluent is separated to recover a cracked hydrocarbon stream and a spent catalyst. The spent catalyst is then contacted, in a stripper, with steam to strip residual hydrocarbons from the spent catalyst, and the spent catalyst is fed from the stripper to a catalyst regenerator where the spent catalyst is regenerated via combustion of coke contained in the spent catalyst to form a regenerated catalyst and combustion products. The regenerated catalyst, containing entrained combustion products from the catalyst regenerator, is then fed to a catalyst standpipe hopper. The entrained combustion products include, for example, nitrogen oxides, sulfur oxides, and carbon oxides. The regenerated catalyst is conditioned, in the catalyst standpipe hopper, by contacting the regenerated catalyst containing entrained combustion products with steam to recover the conditioned catalyst and a vapor stream comprising steam and the combustion products. The conditioned catalyst is then fed to the riser reactor. The vapor stream is fed to the catalyst regenerator, the process further recovering the combustion products and the vapor stream as a flue gas from the catalyst regenerator.

[0008] In some embodiments, the catalyst standpipe hopper contains internals configured to facilitate countercurrent contact of the regenerated catalyst containing entrained combustion products with the steam.

[0009] In various embodiments, the stripper contains internals configured to facilitate countercurrent contact of the spent catalyst with the steam.

[0010] The process of embodiments herein may also include catalyst fluffing. Feeding of the conditioned catalyst to the riser reactor may thus include feeding catalyst from the regenerated catalyst standpipe hopper to the riser reactor via a regenerated catalyst standpipe, the process further comprising fluffing the catalyst within the regenerated catalyst standpipe with air. In other embodiments, the process further comprises fluffing the catalyst within the spent catalyst standpipe with steam.

[0011] Embodiments herein also relate to a system for cracking hydrocarbons. The system includes a riser reactor for contacting a hydrocarbon feedstock with a conditioned cracking catalyst to recover a riser effluent comprising spent catalyst and cracked hydrocarbons. The system further includes a separation system for separating the riser effluent to recover a cracked hydrocarbon stream and a spent catalyst, as well as a stripper for contacting the spent catalyst with steam to strip residual hydrocarbons from the spent catalyst producing a stripped catalyst. Further, the system includes a catalyst regenerator for regenerating the stripped catalyst via combustion of coke contained in the stripped catalyst to form a regenerated catalyst and combustion products. A flow line is provided for feeding regenerated catalyst containing entrained combustion products from the catalyst regenerator to a catalyst standpipe hopper. A conditioning system within the catalyst standpipe hopper is provided for contacting the regenerated catalyst containing entrained combustion products with steam to recover the conditioned catalyst and a vapor stream comprising steam and the combustion products. Additionally, a conditioned catalyst standpipe is provided for feeding the conditioned catalyst to the riser reactor, the system also including a flow line for feeding the vapor stream to the catalyst regenerator, and a flow line for collectively recovering the combustion products and the vapor stream as a flue gas from the catalyst regenerator.

[0012] Other aspects and advantages will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

[0013] The Figure illustrates a block flow diagram of fluidized catalytic cracking (FCC) unit incorporating the claimed process scheme and arrangements according to one or more embodiments disclosed herein.

DETAILED DESCRIPTION

[0014] Embodiments herein relate to processing schemes to reduce flue gas components such as nitrogen oxides, sulfur oxides, oxygen, carbon monoxide and carbon dioxide including nitrogen in FCC systems. More particularly, embodiments herein relate to processing schemes to reduce flue gas components such as nitrogen oxides, sulfur oxides, oxygen, carbon monoxide and carbon dioxide including nitrogen present in FCC regenerated catalysts flowing from a regenerator to a riser reactor.

[0015] The reduction of these undesirable flue gas components is desired for the resulting enhanced performance, increased safety, and reliable operation of the downstream product recovery section. In particular, NO_x contributes to gum formation, which may be a safety hazard in the cold box section of an olefin recovery unit. Per embodiments herein, the addition of internals in a regenerated catalyst standpipe hopper (RCSP Hopper) enables the efficient stripping of these harmful impurities and limiting their introduction into the FCC reactor and product recovery section. The stripping medium may be steam or other industrial inert gases such as nitrogen.

[0016] The purpose is to strip the flue gas components entrained with the catalyst from the regenerator to the RCSP Hopper. Fluffing / stripping steam is used in a countercurrent mode with the catalyst, where the contacting may be conducted with or without internals, such as MODGRID internals. The MODGRID internals, available from Lummus Technology LLC, may enhance efficiency of the fluffing / stripping. While the unique arrangement of MODGRID layers increases the cross-sectional area for the fluffing / stripping operation, other internals may also be used. Steam displaces the flue gas components, thereby reducing the flue gas components.

[0017] Referring now to the Figure, a simplified process flow diagram of systems for cracking hydrocarbons and producing light olefins according to embodiments disclosed

herein is illustrated. The system includes a riser reactor 3 for cracking various hydrocarbon feeds, including directly processed heavy hydrocarbon feeds, for example.

[0018] A hydrocarbon feedstock is injected through one or more feed injectors 2 located near the bottom of riser reactor 3. The hydrocarbon feedstock contacts hot regenerated catalyst introduced through a J-bend 1. The catalyst fed to the first reactor 3 may be a single type of catalyst or a catalyst mixture. For example, a catalyst mixture that may be used can include a first catalyst selective for cracking heavier hydrocarbons, such as a Y-type zeolite-based catalyst, and a second catalyst selective for the cracking of C₄ and naphtha range hydrocarbons for production of light olefins, such as a ZSM-5 or ZSM-11. Other various catalysts useful for cracking hydrocarbons may also be used alone or in admixture.

[0019] In addition to lift steam, a provision may also be made to inject feed streams such as C₄ olefins and naphtha or similar external streams as a lift media to J-bend 1 through a gas distributor 1a located at the Y-section for enabling smooth transfer of regenerated catalyst from J bend 1 to riser reactor 3. J bend 1 may also act as a dense bed reactor for cracking C₄ olefins and naphtha streams into light olefins at conditions favorable for such reactions, such as a WHSV of 0.5 to 50 h⁻¹, a temperature of 640°C to 750°C, and residence times from 2 to 10 seconds.

[0020] The heat required for vaporization of the feed and/or raising the temperature of the feed to the desired reactor temperature, such as in the range from 500°C to about 700°C, and for the endothermic heat (heat of reaction) may be provided by the hot regenerated catalyst coming from the regenerator 17. The pressure in riser reactor 3 is typically in the range from about 1 barg to about 5 barg.

[0021] After a major part of the cracking reaction is completed, the mixture of products, unconverted feed vapors, and spent catalyst flow into a two-stage cyclone system housed in cyclone containment vessel 8. The two-stage cyclone system includes a primary cyclone 4, for separating spent catalyst from vapors. The spent catalyst is discharged into stripper 9 through primary cyclone dip leg 5. Fine catalyst particles entrained with the separated vapors from primary cyclone 4 are separated in second stage cyclone 6. The spent catalyst collected is discharged into stripper 9 via dip leg 7. The vapors from second stage cyclone 6 are vented through a secondary cyclone outlet 12b, which may be connected to plenum 11, and are then routed to a main fractionator

/ gas plant (not shown) for recovery of products, including the desired olefins. If necessary, the product vapors are further cooled by introducing steam or another suitable fluid via distributor line 12a as a quench media.

[0022] The spent catalyst recovered via dip legs 5, 7 undergoes stripping in stripper bed 9 to remove interstitial vapors (the hydrocarbon vapors trapped between catalyst particles) by countercurrent contacting of steam, introduced to the bottom of stripper 9 through a steam distributor 10. Embodiments herein further provide for use of internals 30, such as MODGRID Internals, available from Lummus Technology LLC, to enhance the contact of the steam 10 and the spent catalyst within stripper 9. The spent catalyst is then transferred to regenerator 17 via the spent catalyst standpipe 13a and lift line 15. Spent catalyst slide valve 13b, located on spent catalyst standpipe 13a is used for controlling catalyst flow from stripper 9 to regenerator 17. A small portion of combustion air or nitrogen may be introduced through a distributor 14 to help smooth transfer of spent catalyst. Further, to maintain fluidity of the stripped catalyst and avoid bridging within spent catalyst standpipe 13a, steam 32 may be introduced upstream of slide valve 13b to “fluff” the catalyst.

[0023] Coked or spent catalyst is discharged through spent catalyst distributor 16 in the center of the dense regenerator bed 24. Combustion air is introduced by an air distributor 18 located at the bottom of regenerator bed 24. Coke deposited on the catalyst is then burned off in regenerator 17 via reaction with the combustion air. Regenerator 17, for example, may operate at a temperature in the range from about 640°C to about 750°C and a pressure in the range from about 1 barg to about 5 barg. The catalyst fines entrained along with flue gas are collected in first stage cyclone 19 and second stage cyclone 21 and are discharged into the regenerator catalyst bed through respective dip legs 20, 22. The flue gas recovered from the outlet of second stage cyclone 21 is directed to flue gas line 50 via regenerator plenum 23 for downstream waste heat recovery and/or power recovery.

[0024] The regenerated catalyst is fed to riser reactor 3 via regenerated catalyst standpipe 27, which is in flow communication with J-bend 1. The catalyst flow from regenerator 17 to riser reactor 3 may be regulated by a slide valve 28 located on regenerated catalyst standpipe 27. The opening of slide valve 28 is adjusted to control the catalyst flow to maintain a desired top temperature in riser reactor 3. To maintain

fluidity of the regenerated catalyst and avoid bridging within the regenerated catalyst standpipe 27, a small flow of air 31 may be introduced upstream of slide valve 28 to “fluff” the catalyst.

[0025] The regenerated catalyst is withdrawn from regenerator 17 into a Regenerated Catalyst (RCSP) hopper 26 via withdrawal line 25, which is in flow communication with regenerator 17 and regenerated catalyst standpipe 27. The catalyst bed in the RCSP hopper 26 floats with regenerator 17 bed level. The regenerated catalyst is then transferred from RCSP hopper 26 to reactor 3 via regenerated catalyst standpipe 27, which is in flow communication with J-bend 1. The catalyst flow from regenerator 17 to riser reactor 3 may be regulated by a RCSP slide valve 28 located on regenerated catalyst standpipe 27. A pressure equalization line 29 may also be provided.

[0026] Combustion of coke and other deposits on the spent catalyst within the regenerator may produce a variety of oxygenated combustion products, such as nitrogen oxides, sulfur oxides, carbon monoxide and carbon dioxide. Unconsumed oxygen in the combustion air may also be present in the combustion products. These combustion products are entrained with the catalyst via withdrawal line 25 and are thus contained with and within the catalyst in the regenerated catalyst standpipe hopper.

[0027] The regenerated catalyst is conditioned in embodiments herein to remove the combustion products from the regenerated catalyst within the regenerated catalyst standpipe hopper, thereby minimizing the introduction of oxygen, nitrogen oxides, sulfur oxides, nitrogen, carbon monoxide and carbon dioxide into riser reactor 3, spent catalyst separator 8, and the associated downstream separation system receiving reaction product vapors via outlet 12b. The regenerated catalyst flowing via withdrawal line 25 undergoes conditioning in RCSP hopper 26 to remove the combustion product vapors entrained with the regenerated catalyst particles. Conditioning is conducted by countercurrent contacting of steam 36, or a mixture of steam and air, introduced to the bottom of RCSP hopper 26 through a steam distributor. Embodiments herein further provide for use of internals 34, such as MODGRID Internals, available from Lummus Technology LLC, to enhance the contact of the steam 36 and the regenerated catalyst within RCSP hopper 26. The regenerated catalyst is then transferred to riser reactor 3 via the regenerated catalyst standpipe 27 and J-bend 1.

[0028] As described above with respect to the Figure, a fresh hydrocarbon feed is heated and injected into the riser reactor. The hydrocarbon feed is contacted with the hot regenerated catalyst and cracked into lighter molecules. Cracked feed hydrocarbon vapors and catalyst exits the riser reactor and enters a set of cyclones, wherein the catalyst and hydrocarbon vapors are separated. Hydrocarbon vapors recovered are routed to the main fractionator for product separation. The catalyst flowing from the bottom of the cyclones enters the stripper, wherein the adsorbed hydrocarbon vapor is stripped from the catalyst. The stripped catalyst is routed to the regenerator. Coke (deposits) on the spent catalyst is burned off using combustion air. The flue gas and catalyst enter the cyclones in the regenerator. Most of the flue gas is separated from catalyst in the regenerator cyclones. The flue gas may be fed to a flue gas system to recover heat, cleaned, and released to the atmosphere.

[0029] The regenerated catalyst is then routed to the Regenerated Catalyst Standpipe (RCSP) Hopper. As a small amount of flue gas is entrained with the catalyst, the carry under gas from the RCSP Hopper is essentially flue gas, which has combustion products including Nitrogen Oxides (NO_x), excess oxygen (O₂), including nitrogen and other flue gas components. NO_x, O₂, etc. can lead to unsafe operations under colder conditions. Hence, there is a need to reduce / minimize the concentration of NO_x, Oxygen, etc. for safe and reliable operation.

[0030] Embodiments herein include a steam feed line for providing steam to the RCSP hopper to condition the regenerated catalyst and minimize the amount of nitrogen oxides and other combustion products that flow with the regenerated catalyst to the riser reactor and downstream systems. Internals may be used in the RCSP Hopper to enhance contact of the conditioning steam and the regenerated catalyst. For example, the internals may be MODGRID Internals available from Lummus Technology LLC. The flow rate of steam and height of the internals will be decided on a case-by-case basis depending on feed capacity and quality. By providing the internals, the flue gas components will be efficiently stripped from the catalyst with the help of steam. This will reduce the carry under of undesirable combustion products from the RCSP Hopper into the riser reactor and other downstream systems.

[0031] Embodiments herein may increase steam usage. In addition, embodiments herein may effectively reduce unwanted components in the riser reactor effluents and FCC offgas. Initial testing of embodiments herein shows that total nitrogen is reduced from around 18 mol% (ranging from 15.78 to 19.12 mol %) to around 12 mol% (ranging from 11.24 to 13.57 mol %). Note that nitrogen is one of the components coming along with regenerated catalyst from regenerator to riser-reactor and reactor vapors; other combustion products should be similarly reduced.

[0032] In addition to using internals in the regenerated catalyst standpipe hopper, MODGRID stripper internals and other internals may be used for stripping out hydrocarbon vapors from spent catalyst in the catalyst stripper. Steam is used as stripping media in spent catalyst stripper applications. MODGRID or other internals may be utilized along with MP steam as stripping gas media.

[0033] Since nitrogen is reduced with the help of embodiments herein, the other components of flue gas, such as nitrogen oxides, oxygen, sulfur oxides, and carbon oxides, will be reduced in similar proportion in FCC reactor vapors and subsequently in hydrocarbon products. Safe and reliable operation of downstream recovery sections, including any cold boxes operating at very low temperatures for the separation and recovery of methane, may thus result.

[0034] Efficient stripping of combustion products within the catalyst standpipe hopper may also provide for a reduction in the oxygen converter equipment size and thus catalyst quantity. Further, the ethylene loss across the oxygen converter may be reduced. Additionally, reducing the undesirable combustion products in the product recovery section may enhance recovery section efficiency.

[0035] Furthermore, as the industry is evolving and developing processing schemes to produce chemicals from crude, embodiments herein thus provide for addressing any of these additional impurities that may result. With the present processing scheme, a separate process is not required for either feed treatment or separate product recovery section. Also, additives to remove these impurities may be not necessary.

[0036] Unless defined otherwise, all technical and scientific terms used have the same meaning as commonly understood by one of ordinary skill in the art to which these systems, apparatuses, methods, processes and compositions belong.

- [0037] The singular forms “a,” “an,” and “the” include plural referents, unless the context clearly dictates otherwise.
- [0038] As used here and in the appended claims, the words “comprise,” “has,” and “include” and all grammatical variations thereof are each intended to have an open, non-limiting meaning that does not exclude additional elements or steps.
- [0039] “Optionally” means that the subsequently described event or circumstances may or may not occur. The description includes instances where the event or circumstance occurs and instances where it does not occur.
- [0040] When the word “approximately” or “about” are used, this term may mean that there can be a variance in value of up to $\pm 10\%$, of up to 5% , of up to 2% , of up to 1% , of up to 0.5% , of up to 0.1% , or up to 0.01% .
- [0041] Ranges may be expressed as from about one particular value to about another particular value, inclusive. When such a range is expressed, it is to be understood that another embodiment is from the one particular value to the other particular value, along with all particular values and combinations thereof within the range.
- [0042] While the disclosure includes a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments may be devised which do not depart from the scope of the present disclosure. Accordingly, the scope should be limited only by the attached claims.

CLAIMS

What is claimed is:

1. A process for cracking hydrocarbons, the process comprising:
 - contacting a hydrocarbon feedstock with a conditioned cracking catalyst in a riser reactor to recover a riser effluent comprising spent catalyst and cracked hydrocarbons;
 - separating the riser effluent to recover a cracked hydrocarbon stream and a spent catalyst;
 - contacting, in a stripper, the spent catalyst with steam to strip residual hydrocarbons from the spent catalyst, forming a stripped catalyst;
 - feeding the stripped catalyst to a catalyst regenerator;
 - regenerating, in the catalyst regenerator, the stripped catalyst via combustion of coke contained in the stripped catalyst to form a regenerated catalyst containing entrained combustion products;
 - feeding the regenerated catalyst containing entrained combustion products from the catalyst regenerator to a regenerated catalyst standpipe hopper, wherein the entrained combustion products include nitrogen oxides, sulfur oxides, and carbon oxides including nitrogen;
 - conditioning the regenerated catalyst in the regenerated catalyst standpipe hopper, wherein the conditioning comprises contacting the regenerated catalyst containing entrained combustion products with steam to recover a conditioned catalyst and a vapor stream comprising steam and combustion products;
 - feeding the conditioned catalyst to the riser reactor;
 - feeding the vapor stream to the catalyst regenerator; and
 - recovering the combustion products and the vapor stream as a flue gas from the catalyst regenerator.
2. The process of claim 1, wherein the regenerated catalyst standpipe hopper contains internals configured to facilitate countercurrent contact of the regenerated catalyst containing entrained combustion products including nitrogen with the steam or other industrial inert gases.
3. The process of claim 2, wherein the regenerated catalyst standpipe hopper contains MODGRID internals available from Lummus Technology LLC.

4. The process of any one of the above claims, wherein the stripper contains internals configured to facilitate countercurrent contact of the spent catalyst with the steam.
5. The process of any one of the above claims, wherein the feeding of the conditioned catalyst to the riser reactor comprises feeding the conditioned catalyst from the regenerated catalyst standpipe hopper to the riser reactor via a regenerated catalyst standpipe, the process further comprising fluffing the conditioned catalyst within the regenerated catalyst standpipe with air or steam.
6. The process of any one of the above claims, wherein the feeding of the stripped catalyst from the stripper to the catalyst regenerator comprises feeding stripped catalyst from the stripper to the catalyst regenerator via a spent catalyst standpipe, the process further comprising fluffing the stripped catalyst within the spent catalyst standpipe with steam.
7. A system for cracking hydrocarbons, the system comprising:
 - a riser reactor for contacting a hydrocarbon feedstock with a conditioned cracking catalyst to recover a riser effluent comprising spent catalyst and cracked hydrocarbons;
 - a separation system for separating the riser effluent to recover a cracked hydrocarbon stream and a spent catalyst;
 - a stripper for contacting the spent catalyst with steam to strip residual hydrocarbons from the spent catalyst producing a stripped catalyst;
 - a catalyst regenerator for regenerating the stripped catalyst via combustion of coke contained in the stripped catalyst to form a regenerated catalyst and combustion products;
 - a flow line for feeding regenerated catalyst containing entrained combustion products from the catalyst regenerator to a regenerated catalyst standpipe hopper, wherein the entrained combustion products include nitrogen oxides, sulfur oxides, and carbon oxides including nitrogen;
 - a conditioning system within the regenerated catalyst standpipe hopper for contacting the regenerated catalyst containing entrained combustion products with steam to recover a conditioned catalyst and a vapor stream comprising steam and combustion products;
 - a conditioned catalyst standpipe for feeding the conditioned catalyst to the riser reactor;
 - a flow line for feeding the vapor stream to the catalyst regenerator; and

a flow line for collectively recovering the combustion products and the vapor stream as a flue gas from the catalyst regenerator.

8. The system of claim 7, wherein the conditioning system in the regenerated catalyst standpipe hopper comprises internals configured to facilitate countercurrent contact of the regenerated catalyst containing entrained combustion products with the steam or other industrial inert gases.
9. The system of any one of claims 7-8, wherein the stripper contains internals configured to facilitate countercurrent contact of the spent catalyst with the steam.
10. The system of any one of claims 7-9, further comprising a spent catalyst standpipe for feeding stripped catalyst from the stripper to the catalyst regenerator, and further comprising a flow line for introducing steam into the spent catalyst standpipe.
11. The system of any one of claims 7-10, further comprising a flow line for introducing air into the conditioned catalyst standpipe.