METHODS AND APPARATUSES FOR REMOVING SULFUR COMPOUNDS FROM A HYDROCARBON STREAM

Applicant: UOP LLC, Des Plaines, IL (US)

Inventors: Ralph Charles Norton, Mission Viejo, CA (US); Christine Cavan, Chicago, IL (US)

Appl. No.: 14/296,641
Filed: Jun. 5, 2014

Publication Classification

Int. Cl. C10G 29/00 (2006.01)

U.S. Cl. CPC ......................................... C10G 29/00 (2013.01)

ABSTRACT

Methods and apparatuses are provided for removing sulfur compounds from a hydrocarbon stream. A method includes contacting a hydrocarbon feed stream with a basic aqueous solution in an extractor to produce a sweetened hydrocarbon stream and a rich stream, where the rich stream includes a mercaptan salt. The rich stream is contacted with oxygen in an oxidizer to convert the mercaptan salt into a disulfide and to produce an oxidizer effluent stream. The oxidizer effluent stream is separated into a gas recycle stream and a mixed disulfide stream, and the gas recycle stream is combined with the rich stream.
METHODS AND APPARATUSES FOR REMOVING SULFUR COMPOUNDS FROM A HYDROCARBON STREAM

TECHNICAL FIELD

[0001] The present disclosure generally relates to methods and apparatuses for removing sulfur compounds from hydrocarbon streams, and more particularly relates to methods and apparatuses for removing sulfur compounds from hydrocarbon streams with low vented gaseous emissions.

BACKGROUND

[0002] Many hydrocarbon streams include sulfur compounds when extracted from the earth, or when produced from other sources. The sulfur compounds are removed from hydrocarbon streams for a variety of reasons, including limits imposed on the amount of sulfur compounds that may be present in many hydrocarbon products by regulatory bodies. The sulfur compounds may also poison catalysts in further processing of the hydrocarbons, the sulfur compounds may impart an undesirable odor that reduces the value of the hydrocarbons products, and the sulfur compounds may be hazardous. Therefore, methods and apparatus have been developed for removing sulfur compounds from hydrocarbon streams.

[0003] The methods and apparatus often provide a sweetened hydrocarbon stream, where the term “sweetened” may be used because of the reduced odor compared to the unsweetened hydrocarbon stream. However, the various processes that remove sulfur compounds tend to produce vented gaseous streams. The sulfur compounds may be extracted from the vent gases, but the extraction process is not perfect and some sulfur compounds are discharged with the vent gases. Regulatory bodies are limiting the amount of sulfur compounds that may be discharged with vent gases, and the public desires reduced venting of sulfur compounds because of the strong odor and because of other reasons.

[0004] Accordingly, it is desirable to develop methods and apparatus for removing sulfur compounds from hydrocarbon streams with reduced venting of sulfur compounds. In addition, it is desirable to reduce the total amount of gases vented when removing sulfur compounds from hydrocarbon streams. Furthermore, other desirable features and characteristics of the present embodiment will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background.

BRIEF SUMMARY

[0005] Methods and apparatuses for removing sulfur compounds from hydrocarbon streams are provided. In an exemplary embodiment, a method includes contacting a hydrocarbon feed stream with a basic aqueous solution in an extractor to produce a sweetened hydrocarbon stream and a rich stream, where the rich stream includes a mercaptan salt. The rich stream is contacted with oxygen in an oxidizer to convert the mercaptan salt into a disulfide in an oxidizer effluent stream. The oxidizer effluent stream is separated into a gas recycle stream and a mixed disulfide stream, and the gas recycle stream is combined with the rich stream.

[0006] In accordance with another exemplary embodiment, a method for removing sulfur compounds from a hydrocarbon stream includes converting a mercaptan in a hydrocarbon feed stream into a disulfide in a sulfur compound removal unit. A sweetened hydrocarbon stream is discharged from the sulfur compound removal unit, where the concentration of sulfur containing compounds in the sweetened hydrocarbon stream is lower than in the hydrocarbon feed stream. A gas recycle stream is recycled such that intentionally vented gaseous discharges are controlled to about 1 volume percent or less of the volume of the sweetened hydrocarbon stream during a time period of about 24 hours or more.

[0007] In accordance with a further exemplary embodiment, an apparatus for removing sulfur compounds from a hydrocarbon stream includes an oxidizer coupled to an extractor. An oxidizer effluent separator is coupled to the oxidizer, where the oxidizer effluent separator is configured to produce a gas recycle stream and a mixed disulfide stream, and where the gas recycle stream is coupled to the oxidizer. A disulfide separator is coupled to the mixed disulfide stream.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Various embodiments will hereinafter be described in conjunction with the FIGURE, which is a schematic diagram of an exemplary embodiment of an apparatus and method for removing sulfur compounds from a hydrocarbon stream.

DETAILED DESCRIPTION

[0009] The following detailed description is merely exemplary in nature and is not intended to limit the application and uses of the embodiment described. Furthermore, there is no intention to be bound by any theory presented in the preceding background or the following detailed description.

[0010] The various embodiments described herein relate to methods and apparatuses for removing sulfur compounds from a hydrocarbon stream. A hydrocarbon feed stream includes volatile, odiferous sulfur containing compounds, such as mercaptans and possibly hydrogen sulfide. The sulfur compounds are removed with a basic aqueous solution, such as caustic, where the sulfur compounds react with the caustic and an oxidizing agent, in the presence of a catalyst, to produce non-volatile disulfides. After removal of the sulfur compounds, the discharged hydrocarbons are referred to as a sweetened hydrocarbon stream. The oxygen in air is often used as the oxidizing agent, and excess gases from the air have historically been vented to the atmosphere. The vented gases have contained low concentrations of the odiferous, volatile sulfur compounds. The vented gases can be essentially eliminated by implementing a gas recycle stream that collects excess gases and recycles them to oxidize additional sulfur compounds. Oxygen reacts with the sulfur containing compounds, and the oxygen is gradually removed from the system. Nitrogen (a major component of air) gradually dissolves in the basic aqueous solution and is discharged with the sweetened hydrocarbon stream. The oxygen concentration from the gas recycle stream is measured and adjusted to maintain a desired gas recycle oxygen concentration, where oxygen and/or nitrogen may be added as needed to maintain the desired oxygen concentration and a sufficient volume of gas for the process. Use of the gas recycle stream can reduce the venting of excess gases to zero in some embodiments.

[0011] Reference is made to the exemplary embodiment illustrated in the FIGURE. Sulfur containing compounds are removed from an initial hydrocarbon stream 10 in a sulfur compound removal unit 12. The initial hydrocarbon stream
10 includes hydrocarbons and sulfur containing compounds, such as various mercaptans and possibly hydrogen sulfide in some embodiments. In an exemplary embodiment, the hydrocarbon feed stream includes hydrocarbon compounds having 3 or 4 carbon atoms, so the initial hydrocarbon stream 10 may be used as liquefied petroleum gas (LPG). In some embodiments, about 90 volume percent or more of the hydrocarbon feed stream is hydrocarbons having 3 or 4 carbon atoms. In this description, all volume percentages are based on the volume measured at a pressure of 1 atmosphere and a temperature of 0 degrees centigrade (°C). The sulfur compound removal unit 12 may be used to remove sulfur compounds from a hydrocarbon feed stream 18 including hydrocarbons generally having more than 3 or 4 carbon atoms, or from hydrocarbon feed streams 18 including hydrocarbons generally having less than 3 or 4 carbon atoms, or from hydrocarbon feed streams 18 that include a mixture of hydrocarbons having a wide range of carbon atoms.

Reference is made to the FIGURE. The initial hydrocarbon stream 10 is optionally introduced into a prewash unit 14 to remove hydrogen sulfide. Several different types of prewash units 14 can be used, including caustic washing, amine treatment, and sodium carbonate treatment units. In an exemplary embodiment, the prewash unit 14 mixes the initial hydrocarbon stream 10 with a fresh prewash stream 16, where the fresh prewash stream 16 is an aqueous caustic (e.g., sodium hydroxide) solution at a concentration of from about 5 weight percent (wt. %) to about 15 wt. % caustic in water. The caustic reacts with the hydrogen sulfide to produce a spent prewash stream 20 that includes sodium hydrosulfide and sodium sulfide, both of which are soluble in water. A hydrocarbon feed stream 18 containing hydrocarbons and some mercaptans exits the prewash unit 14, and the spent prewash stream 20 containing the prewash material and reaction products, such as caustic and sodium hydrosulfide, also exits the prewash unit 14. The caustic in the prewash unit 14 may be recycled and gradually discharged and replaced with fresh caustic. Operating conditions for the prewash unit 14 are variable, but typically include ambient temperatures and pressures sufficient to keep the initial hydrocarbon stream 10 liquid. For example, temperatures from about 10 degrees centigrade (°C) to about 60° C, and more typically from about 30 to about 50°C, and pressures ranging from about 5 bars to about 30 bars can be used. In alternate embodiments, the hydrocarbon feed stream 18 includes very little or no hydrogen sulfide, so no prewash unit 14 is needed or used, and the hydrocarbon feed stream 18 is charged directly into an extractor 22 of the sulfur compound removal unit 12, as described below.

In one embodiment, the hydrocarbon feed stream 18 is treated in the extractor 22 to remove any remaining mercaptans by reacting them with caustic to produce mercaptan salts. The prewash unit 14, if present, is fluidly coupled to the extractor 22. The hydrocarbon feed stream 18 and a basic aqueous solution 24 are charged into the extractor 22, where the hydrocarbon feed stream 18 and the basic aqueous solution 24 are in the liquid phase. The basic aqueous solution 24 may be a solution of caustic and water in some embodiments, but it can also be an aqueous ammonia solution or other basic aqueous solutions. In an exemplary embodiment, the basic aqueous solution 24 is charged near the top of the extractor 22, as within the top third of the extractor 22, and the hydrocarbon feed stream 18 is charged near the bottom of the extractor 22, such as in the bottom third of the extractor 22.

The basic aqueous solution 24 intimately contacts the hydrocarbon feed stream 18 in the extractor 22, and the mercaptans in the hydrocarbon feed stream 18 are reacted to form mercaptan salts. A sweetened hydrocarbon stream 26 exits the extractor 22, where the concentration of sulfur containing compounds is lower in the sweetened hydrocarbon stream 26 than in the hydrocarbon feed stream 18. In some embodiments, the concentration of sulfur containing compounds in the sweetened hydrocarbon stream 26 is about 10 parts per million by volume or less, and the concentration of sulfur containing compounds in the hydrocarbon feed stream 18 may be about 2 percent by volume or more. The sweetened hydrocarbon stream 26 may then be used or further processed.

The concentration of the basic aqueous solution 24 may vary, but in an exemplary embodiment the basic aqueous solution 24 ranges from about 5 to about 25 wt. % caustic in water. The basic aqueous solution 24 generally does not form a solution or a suspension with the hydrocarbons in the hydrocarbon feed stream 18, and the caustic solution is denser than the hydrocarbons in the hydrocarbon feed stream 18. Therefore, the basic aqueous solution 24 flows downward through the extractor 22 as hydrocarbons in the hydrocarbon feed stream 18 flow upward through the extractor 22. In one embodiment, the extractor 22 includes a plurality of trays configured to direct the denser basic aqueous solution 24 through a tortuous path downward while the hydrocarbon feed stream 18 is directed through a tortuous path upward, where the trays are designed to mix and contact the two streams as they flow in a counter-current manner. In an alternate embodiment, the extractor 22 includes packing or other structures to mix the basic aqueous solution 24 and the hydrocarbon feed stream 18 as they flow past each other. The extractor 22 is sized to provide sufficient stages to react the mercaptans with the basic aqueous solution 24, such as about 2 to about 6 stages or more. Exemplary operating conditions for the extractor 22 include a temperature of from about 10°C to about 60°C and a pressure sufficient to keep the hydrocarbon feed stream 18 in the liquid phase, such as from about 5 bars to about 30 bars.

A rich stream 28 exits the extractor 22, and includes the basic aqueous solution 24 and mercaptan salts. Oxygen is added to the rich stream 28 to react with the mercaptan salts, where the oxygen may be added before or in an oxidizer 32, described below. In an exemplary embodiment, the oxygen is added in an oxygen supply stream 30, where the oxygen supply stream 30 may be air or other oxygen-containing gases. The oxygen supply stream 30 may be used during start-up periods, or during upset periods, but the oxygen supply stream 30 may be closed during standard operating periods. As such, the oxygen supply stream 30 may be a temporary source of oxygen that is only used when needed and not on a day to day basis. A gas recycle stream 50 can also be used to supply oxygen to the rich stream 28, where the gas recycle stream 50 is more fully described below. The added oxygen and water from the rich stream 28 react with the mercaptan salts in the oxidizer 32 to form disulfides and caustic, so the oxidizer 32 is fluidly coupled to the extractor 22. The unaided reaction rate for the oxidation of the mercaptan salts is slow, and therefore an oxidation catalyst 34 may be used to speed the oxidation reaction to produce the disulfides. The oxidation catalyst 34 may be added to the rich stream 28 or other streams in a recirculation loop for the basic aqueous solution 24, where the oxidation catalyst 34 may be added on
an as needed basis. In an exemplary embodiment, the oxidation catalyst 34 is added to the rich stream 28 upstream from the oxidizer 32, but the oxidation catalyst 34 could be added at other locations as well.

[0016] In some embodiments, the oxidation catalyst 34 is a metal chelate, and can be in liquid or solid form. Several chelating agents can be used, such as phthalocyanines, tetraphenylporphyrins, or tetrahydridophosphorazines. Many chelating agents are not readily soluble in water, but water solubility can be increased by brominating, sulfonating, or carboxylating the chelating agents. In some embodiments, the metal is one or more of iron, cobalt, manganese, molybdenum, or vanadium. Water soluble oxidation catalysts 34 may be used, as mentioned above, but insoluble forms of the oxidation catalyst 34 can be used in suspension or supported on a substrate that is either held in a fixed position in the oxidizer 32, or maintained in a slurry with the basic aqueous solution 24. Suitable substrates for the oxidation catalyst 34 include activated carbon, charcoal granules, thermoplastic polymers, exchange resins, and a wide variety of other materials. One exemplary oxidation catalyst 34 is iron phthalocyanine tetrasulphonate, but many other embodiments of an oxidation catalyst 34 are possible.

[0017] The rich stream 28 including the mercaptan salts, oxygen, and the oxidation catalyst 34 is heated and enters the oxidizer 32. The oxidizer 32 may include a packed bed 36, trays, fixed beds, or other structures that keep the basic aqueous solution 24 and the water insoluble disulfides well mixed as they flow through the oxidizer 32. The mercaptan salts are oxidized to disulfides, so substantially no mercaptans remain in an oxidizer effluent stream 38 exiting the oxidizer 32. For example the concentration of mercaptans in an oxidizer effluent stream 38 may be about 1000 parts per million by weight or less. Exemplary operating conditions for the oxidizer 32 include a pressure of from about 1 bar to about 10 bars, and a temperature of from about 30° C. to about 60° C. The basic aqueous solution 24 may be replenished with fresh basic aqueous solution 24 as needed (not illustrated).

[0018] In an exemplary embodiment, the oxidizer effluent stream 38 exits the oxidizer 32 and may flow in two different routes. In a start-up or upset mode, the oxidizer effluent stream 38 may flow to a disulfide separator 80, such as when the oxygen supply stream 30 is in use. However, during normal operations the oxidizer effluent stream 38 may flow to a recycle pump 40, and then to an oxidizer effluent separator 42. Therefore, the oxidizer 32 is fluidly coupled to the disulfide separator 80 and to the oxidizer effluent separator 42. In some embodiments, the oxidizer effluent stream 38 may flow to both the recycle pump 40 and the disulfide separator 80, so the oxidizer effluent stream 38 is split. The oxidizer effluent stream 38 may be split, with a partial recycle of the gas recycle stream 50, described more fully below. The recycle pump 40 may be used to increase the pressure in the oxidizer effluent separator 42 to a pressure higher than that in the rich stream 28 and in the oxidizer 32. The recycle pump 40 is a pump that is capable of pressurizing a mixed gas/liquid stream, such as diaphragm or piston pump. The oxidizer effluent stream 38 includes liquid intermixed with excess gases, including oxygen, as well as some hydrocarbons that remain in solution or are otherwise carried into the oxidizer 32. The liquids minimize the potential and possible severity of a flash or ignition from the mixed hydrocarbons and oxygen. The oxidizer effluent stream 38 includes basic aqueous solution 24, disulfides that are not soluble in the basic aqueous solution 24, and excess oxygen and other non-condensables from the oxygen supply stream 30 or from other oxygen sources, described below. The basic aqueous solution 24 and the disulfides form a liquid layer in the oxidizer effluent separator 42, and the oxidizer effluent separator 42 is fluidly coupled to the disulfide separator 80. In an exemplary embodiment, a back pressure control valve 46 is positioned between the oxidizer effluent separator 42 and the disulfide separator 80, and is used to maintain an oxidizer effluent separator pressure greater than the pressure in the oxidizer 32, as described below. The disulfide separator 80 has no agitation and has a sufficient volume to allow the water insoluble disulfides to split from the basic aqueous solution 24. In an exemplary embodiment, the disulfide separator 80 has a residence time of from about 0.5 to about 3 hours. Any excess gases, such as excess nitrogen or oxygen from the oxygen supply stream 30, may be vented from the disulfide separator 80 in a disulfide separator vent 84. The disulfide separator vent 84 can be directed to a scrubber or other pollution control device, and optionally includes a liquids entrainment separator (not illustrated) to prevent discharge of aqueous material or disulfides. The disulfide oil is less dense than the basic aqueous solution 24, so the upper layer of disulfide oil exits near the top of the disulfide separator 80 in a disulfide stream 82, and the basic aqueous solution 24 is recovered from the bottom of the disulfide separator 80. The disulfide stream 82 is discharged from the sulfur compound removal unit 12, and may be further processed or otherwise used. The basic aqueous solution 24 is then pressurized with a basic aqueous solution pump 48, and returned to the extractor 22. The basic aqueous solution 24 recirculates through the extractor 22, the oxidizer 32, and the disulfide separator 80, which are all fluidly coupled together. The oxidizer 32 and the disulfide separator 80 work together as a basic aqueous solution regeneration system for recirculation.

[0020] The gases from the oxidizer effluent separator 42 are discharged into the gas recycle stream 50, where the gas recycle stream 50 is then directed into the oxidizer 32 with the rich stream 28. The gas recycle stream 50 may be combined with the rich stream 28 before the oxidizer 32 or within the oxidizer 32 in various embodiments. In an exemplary embodiment, the oxidizer effluent separator 42 includes a level controller 52 to control the liquid level in the oxidizer effluent separator 42. The level controller 52 works with the back pressure control valve 46 to control the liquid level and pressure in the oxidizer effluent separator 42. The liquid level in the oxidizer effluent separator 42 is controlled to within a desired liquid level range, and the oxidizer effluent separator pressure is controlled to within a desired oxidizer effluent separator pressure. In an exemplary embodiment, the desired liquid level range is from about 30 percent to about 70 percent of the volume of oxidizer effluent separator 42, or about 20 percent to about 80 percent of the volume of the oxidizer effluent separator 42 in another embodiment. The desired oxidizer effluent separator pressure is from about 0 to about 2 bars greater than the oxidizer pressure.

[0021] When the liquid level in the oxidizer effluent separator 42 is too low, the level controller 52 opens a level control valve 54 in the gas recycle stream 50, so the pressure in the
oxidizer effluent separator 42 declines as gas is discharged from the oxidizer effluent separator 42 into the gas recycle stream 50. As the pressure in the oxidizer effluent separator 42 declines, the back pressure control valve 46 closes, so liquids are not allowed to drain from the oxidizer effluent separator 42. The liquid level then rises as additional liquids from the oxidizer effluent stream 38 enter the oxidizer effluent separator 42. If the liquid level in the oxidizer effluent separator 42 is too high, the level controller 52 closes the level control valve 54 so gases cannot escape. This causes the pressure in the oxidizer effluent separator to increase as the oxidizer effluent stream 38 continues to discharge into the oxidizer effluent separator 42. The increased pressure causes the back pressure control valve 46 to open and allows liquid to drain from the oxidizer effluent separator 42. The back pressure control valve 46 is set such that the oxidizer effluent separator pressure is greater than the oxidizer pressure, and so the pressure of the gas recycle stream 50 is higher than the pressure of the rich stream 28. The gas recycle stream 50 will flow into the rich stream 28 because the pressure in the gas recycle stream 50 is higher than the pressure in the rich stream 28. In many embodiments, the level control valve 54 and the back pressure control valve 46 control the level in the oxidizer effluent separator 42 by changing to a more open or closed position. As such, the level control valve 54 and back pressure control valve 46 may or may not completely open or close to control the level, so references herein to “opening” or “closing” can be interpreted as moving towards a more open or closed position, respectively. In an exemplary embodiment, the pressure in the disulfide separator 80 is from about 2 bars to about 4 bars, and the pressure in the oxidizer 32 is from about 0 to about 2 bars higher than the pressure in the disulfide separator 80. The pressure in the rich stream 28 is from about 0 to about 1 bar higher than the pressure in the oxidizer 32. The gas recycle stream 50 may include one or more flow meters and flow valves (not illustrated) to regulate the flow into the rich stream 28.

[0022] In some embodiments, an oxygen analyzer 56 is positioned to measure the oxygen concentration in the gas recycle stream 50, where the oxygen analyzer 56 measures the gas recycle stream oxygen concentration. An oxygen supply line 58 and a nitrogen supply line 60 are used to add oxygen and nitrogen, respectively, to control the gas recycle oxygen concentration to within a desired gas recycle oxygen concentration. In an alternate embodiment, an air supply line (not illustrated) may be used in place of or as a supplement to the oxygen supply line 58 and/or the nitrogen supply line 60. The oxygen analyzer 56 may be positioned downstream from the entrance of the oxygen supply line 58 and the nitrogen supply line 60 in some embodiments, but in other embodiments the oxygen analyzer 56 may be positioned in other locations. Oxygen reacts with the mercaptan salts and is thereby removed from the gas recycle stream 50, and nitrogen may gradually dissolve in the basic aqueous solution 24, and then evaporate and escape from the sulfur compound removal unit 12 in the sweetened hydrocarbon stream 26. Therefore, some oxygen and some nitrogen may be needed to maintain an adequate gas supply for the gas recycle stream 50 as the gas recycle stream 50 is recycled through the process.

[0023] In an exemplary embodiment, the desired gas recycle oxygen concentration is about the same as that in air (about 21 volume percent oxygen). For example, the desired gas recycle oxygen concentration may be from about 20 volume percent to about 22 volume percent, or from about 18 volume percent to about 24 volume percent in various embodiments. However, in other embodiments, the desired gas recycle oxygen concentration may be higher or lower than that of air.

[0024] The gas recycle stream 50 may be used to supply all the oxygen needed in the oxidizer 32, such that vented gaseous emissions from the disulfide separator vent 84 are eliminated during normal operations. As such, the disulfide separator 80 may be operated with substantially no vented gaseous emissions for a period of about 24 hours or more, or about 48 hours or more, or about 1 week or more, or about 1 month or more during standard operations in various embodiments. Standard operations include when the hydrocarbon feed stream 18 is being introduced to the extractor 22 and contacted with the basic aqueous solution 24 so that mercaptans in the hydrocarbon feed stream 18 are converted into disulfides, and when the level of gases in the gas recycle stream 50 are sufficient for proper liquid level and pressure control in the oxidizer effluent separator 42. In some sulfur compound removal units 12, gases vented from the disulfide separator 80 are most of the emissions from the sulfur compound removal unit 12, such as about 80 volume percent or greater. Fugitive emissions from minor leaks in flanges, pump seals, etc. are not considered intentionally vented gaseous emissions because fugitive emissions are not intentionally vented. In an alternate embodiment, intentionally vented gaseous discharges from the sulfur compound removal unit 12 may be less than about 1 volume percent of the volume of the hydrocarbon feed stream 18 introduced to the extractor 22 during a fixed time period, wherein such emissions are reduced by a total or partial recycle of the gas recycle stream 50. The fixed time period may be about 1 hour, or about 24 hours, or about 1 week, or many other fixed time periods in various embodiments. In yet another embodiment, the intentionally vented gases discharged from the sulfur compound removal unit 12 may be less than about 0.1 volume percent of the volume of the hydrocarbon feed stream 18 introduced to the extractor 22 during the fixed time period.

[0025] While at least one exemplary embodiment has been presented in the foregoing detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the application in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing one or more embodiments, it being understood that various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope, as set forth in the appended claims.

What is claimed is:

1. A method for removing sulfur compounds from a hydrocarbon stream comprising:
   contacting a hydrocarbon feed stream with a basic aqueous solution in an extractor to produce a sweetened hydrocarbon stream and a rich stream, wherein the rich stream comprises a mercaptan salt;
   contacting the rich stream with oxygen in an oxidizer to convert the mercaptan salt into a disulfide and to produce an oxidizer effluent stream comprising the disulfide;
   separating the oxidizer effluent stream into a gas recycle stream and a mixed disulfide stream and;
combining the gas recycle stream with the rich stream, wherein the gas recycle stream comprises oxygen.

2. The method of claim 1 further comprising:
pressurizing the oxidizer effluent stream prior to separating the oxidizer effluent stream, wherein the oxidizer effluent stream is pressurized to a pressure in the oxidizer effluent stream greater than a pressure in the oxidizer.

3. The method of claim 1 further comprising:
measuring an oxygen concentration in the gas recycle stream; and
controlling the oxygen concentration in the gas recycle stream to within a desired gas recycle oxygen concentration.

4. The method of claim 3 wherein controlling the oxygen concentration in the gas recycle stream comprises adding oxygen to the gas recycle stream.

5. The method of claim 3 wherein controlling the oxygen concentration in the gas recycle stream comprises adding nitrogen to the gas recycle stream.

6. The method of claim 1 wherein contacting the hydrocarbon feed stream with the basic aqueous solution comprises contacting the hydrocarbon feed stream with the basic aqueous solution wherein the basic aqueous solution comprises a caustic solution.

7. The method of claim 1 wherein:
contacting the rich stream with oxygen in the oxidizer comprises contacting the rich stream with oxygen in the oxidizer in the presence of a catalyst.

8. The method of claim 7 wherein contacting the rich stream with oxygen in the oxidizer comprises contacting the rich stream with oxygen in the oxidizer in the presence of the catalyst, wherein the catalyst comprises a metal chelate, and wherein the metal chelate comprises one or more of iron, cobalt, manganese, molybdenum, and vanadium.

9. The method of claim 1 further comprising:
separating the mixed disulfide stream into a disulfide stream and the basic aqueous solution in a disulfide separator.

10. The method of claim 9 further comprising:
limiting vented gases from the disulfide separator to zero emissions for a period of about 24 hours or greater while contacting the hydrocarbon feed stream with the basic aqueous solution.

11. The method of claim 1 wherein contacting the hydrocarbon feed stream with the basic aqueous solution comprises contacting the hydrocarbon feed stream with the basic aqueous solution wherein the hydrocarbon feed stream comprises about 90 volume percent or more hydrocarbons having either 3 or 4 carbon atoms.

12. The method of claim 1 wherein separating the oxidizer effluent stream into the gas recycle stream and the mixed disulfide stream comprises separating the oxidizer effluent stream in an oxidizer effluent separator, the method further comprising:
controlling a liquid level in the oxidizer effluent separator to within a desired liquid level range.

13. A method for removing sulfur compounds from a hydrocarbon stream comprising:
converting a mercaptan in a hydrocarbon feed stream into a disulfide in a sulfur compound removal unit;
discharging a sweetened hydrocarbon stream from the sulfur compound removal unit, wherein the concentration of sulfur containing compounds in the sweetened hydrocarbon stream is lower than in the hydrocarbon feed stream; and
recycling a gas recycle stream such that intentionally vented gaseous discharges from the sulfur compound removal unit are controlled to about 1 volume percent or less of a volume of the sweetened hydrocarbon stream during a time period of about 24 hours or more.

14. The method of claim 13 wherein converting the mercaptan in the hydrocarbon feed stream into the disulfide further comprises:
contacting the hydrocarbon feed stream with a basic aqueous solution to form the sweetened hydrocarbon stream and a rich stream, wherein the rich stream comprises a mercaptan salt; and
oxidizing the mercaptan salt in the rich stream with oxygen in the gas recycle stream to produce the disulfide in an oxidizer effluent stream.

15. The method of claim 14 further comprising:
separating the oxidizer effluent stream into the gas recycle stream and a mixed disulfide stream.

16. The method of claim 15 further comprising:
separating the mixed disulfide stream into a disulfide stream and the basic aqueous solution in a disulfide separator; and
discharging the disulfide stream.

17. The method of claim 16 further comprising:
limiting vented gases from the disulfide separator to zero emissions for about 24 hours or more while converting the mercaptan in the hydrocarbon feed stream into the disulfide.

18. The method of claim 13 further comprising:
measuring a gas recycle oxygen concentration; and
controlling the gas recycle oxygen concentration to within a desired gas recycle oxygen concentration.

19. The method of claim 18 wherein controlling the gas recycle oxygen concentration comprises adding oxygen to the gas recycle stream.

20. An apparatus for removing sulfur compounds from a hydrocarbon stream comprising:
an extractor;
an oxidizer coupled to the extractor;
an oxidizer effluent separator coupled to the oxidizer, where the oxidizer effluent separator in configured to produce a gas recycle stream and a mixed disulfide stream, and wherein the gas recycle stream is coupled to the oxidizer; and
a disulfide separator coupled to the mixed disulfide stream.