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(54) Title: CONTROL OF ACID GAS LOADING WITHIN GAS PROCESSING SYSTEM

(57) Abstract: Techniques described herein relate to a method for controlling acid gas loading within a gas processing system. The method includes contacting a sour gas stream including acid gases with a solvent stream within a number of co-current contacting systems to generate a sweetened gas stream and a rich solvent stream including absorbed acid gases. The method also includes measuring the gas flow rate and the solvent flow rate, as well as measuring the liquid and/or gas inlet temperatures and outlet temperatures for each co-current contacting system. The method further includes determining the amount of acid gases absorbed by the solvent stream within each co-current contacting system based on the measured parameters, in combination with the heat of reaction between the acid gases and the solvent stream, as well as adjusting operating parameters corresponding to the gas processing system based on the determined amount of absorbed acid gases.



WO 2022/165451 A1

CONTROL OF ACID GAS LOADING WITHIN GAS PROCESSING SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

5 [0001] This application claims the priority benefit of United States Provisional Patent Application No. 63/142745, filed January 28, 2021, entitled CONTROL OF ACID GAS LOADING WITHIN GAS PROCESSING SYSTEM, the entirety of which is incorporated by reference herein.

FIELD

10 [0002] The techniques described herein relate to the oil and gas field and, more specifically, to gas processing systems. More particularly, the techniques described herein relate to controlling acid gas loading within gas processing systems including co-current flow schemes.

BACKGROUND

15 [0003] This section is intended to introduce various aspects of the art, which may be associated with embodiments of the present techniques. This discussion is believed to assist in providing a framework to facilitate a better understanding of particular aspects of the present techniques. Accordingly, it should be understood that this section should be read in this light, and not
20 necessarily as admissions of prior art.

[0004] The production of hydrocarbons from a reservoir oftentimes carries with it the incidental production of non-hydrocarbon gases. Such gases include contaminants such as hydrogen sulfide (H₂S) and carbon dioxide (CO₂). When H₂S and CO₂ are produced as part of a hydrocarbon gas stream, the raw gas stream is sometimes referred to as “sour gas.” The H₂S and
25 CO₂ are often referred to together as “acid gases.”

[0005] In addition to hydrocarbon production streams, acid gases may be associated with synthesis gas streams, or with refinery gas streams. Acid gases may also be present within so-called flash-gas streams in gas processing facilities. Further, acid gases may be generated by the combustion of coal, natural gas, or other carbonaceous fuels.

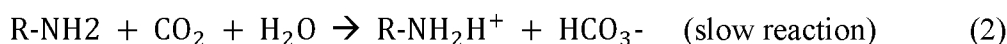
[0006] Natural gas streams may contain not only H₂S and CO₂, but also other “acidic” impurities. These include mercaptans and other trace sulfur compounds (e.g., COS). In addition, natural gas streams may contain water. Such impurities are often removed prior to industrial or residential use. For example, natural gas streams are typically purified to concentrations of less than 4 parts per million (ppm) H₂S and less than 2-3 volume percent (vol. %) CO₂ prior to sale. The extent to which such impurities must be removed is dictated by pipeline regulations, which help to ensure public safety and maintain the integrity of the pipeline by reducing corrosion.

[0007] Acid gas removal is an expensive and equipment-intensive process. The removal of H₂S from natural gas streams is especially complicated due to the safety, health, and environmental considerations when working with toxic H₂S and the processing of sulfur by-products into solid sulfur, or the injection of H₂S-rich gas through acid gas injection methods.

[0008] Various processes have been devised to remove acid gases from a raw natural gas stream. For example, the raw natural gas stream may be treated with a solvent. Solvents may include chemical solvents such as amines. Examples of amines used in sour gas treatment include monoethanol amine (MEA), diethanol amine (DEA), and methyl diethanol amine (MDEA).

[0009] Physical solvents are sometimes used in lieu of chemical solvents. Examples include SELEXOL™ (available from Dow Chemical Company) and RECTISOL® (available from The Linde Group). However, chemical solvents are generally more effective than physical solvents, particularly at feed gas pressures below about 300 psia (2.07 MPa). In some instances, hybrid solvents, meaning mixtures of physical and chemical solvents, have been used. An example is Sulfinol®.

[0010] Chemical solvents, such as amine-based solvents, rely on a chemical reaction between the solvent and the acid gases within the natural gas stream. The reaction process is sometimes referred to as “gas sweetening.” As an example, the reactions of acid gases with tertiary amines (R₁R₂R₃-N) are shown below in Equations (1) and (2).



[0011] As shown in Equation (1), the reaction of H_2S with the amine is inherently very fast and is often considered instantaneous with respect to diffusion and other mass transfer limitations. However, as shown in Equation (2), the reaction of CO_2 is somewhat slower. The difference in these reaction rates can be utilized to selectively remove one impurity over another within a gas processing system. Note that primary and secondary amines offer a faster reaction route with CO_2 to form carbamates. Consequently, those amines normally cannot be used for selective H_2S removal. Exceptions to this include “sterically-hindered” amines, which prevent the CO_2 from reacting with the amino hydrogen to form carbamates.

[0012] Selective H_2S removal is becoming a significant consideration for natural gas processing facilities. This is due to the fact that the oil and gas industry has seen an increase in natural gas assets with high H_2S concentrations but low CO_2 concentrations. As a result, many natural gas assets, such as, for example, shale gas, require H_2S removal with little to no CO_2 removal. Conversely, natural gas assets occasionally have an abundance of CO_2 but only a small amount of H_2S . In such cases, it may be desirable to produce a sweet, low BTU fuel gas by selectively removing the H_2S . To accomplish this, a solvent with a high selectivity for H_2S may be used. The “ H_2S selectivity” of the solvent is defined as the ratio of H_2S removal to CO_2 removal, which is a function of the respective reaction rates. A high H_2S selectivity may be obtained by using solvents that have a slower reaction rate with CO_2 . Similarly, the contact time of the gas and liquid phases can be minimized to enhance H_2S uptake over CO_2 .

[0013] In general, it is beneficial to monitor the total amount of acid gas absorbed during a selective acid gas removal process, as well as potentially the amount of H_2S absorbed versus the amount of CO_2 absorbed, since such information can be used to optimize the performance of the corresponding gas processing system. However, according to current gas processing techniques, it is challenging to determine the total amount of acid gas absorbed during the acid gas removal process. Determining the amount of H_2S absorbed is relatively trivial and can be accomplished using H_2S analyzers. However, determining the amount of CO_2 absorbed is more difficult due to small differences in gas phase concentration. Moreover, CO_2 is typically the dominant component in terms of acid gas loading considerations. Furthermore, while analysis of the liquid phase can determine the amount of H_2S and CO_2 absorbed, current techniques for analyzing the liquid phase are more costly and time-consuming and, thus, not suitable for online process control.

Accordingly, there exists a need for improved acid gas loading control techniques for gas processing systems.

SUMMARY

5 **[0014]** An embodiment described herein provides a method for controlling acid gas loading within a gas processing system. The method includes contacting a sour feed gas stream including acid gases with a solvent stream within co-current contacting systems of the gas processing system to generate a sweetened gas stream and a rich solvent stream including absorbed acid gases, as well as removing the absorbed acid gases from the rich solvent stream within a regenerator of the
10 gas processing system to regenerate the solvent stream. The method includes measuring a gas flow rate for the sour feed gas stream and a solvent flow rate for the solvent stream via corresponding flow meters within the gas processing system, measuring at least one of a liquid inlet temperature or a gas inlet temperature for each co-current contacting system via a corresponding temperature sensor positioned upstream of each co-current contacting system, and
15 measuring at least one of a liquid outlet temperature or a gas outlet temperature for each co-current contacting system via a corresponding temperature sensor positioned downstream of each co-current contacting system. The method also includes determining an amount of acid gases absorbed by the solvent stream within each co-current contacting system based on the gas flow rate, the solvent flow rate, the at least one of the liquid inlet temperature or the gas inlet
20 temperature, and the at least one of the liquid outlet temperature or the gas outlet temperature, in combination with the heat of reaction between the acid gases and the solvent stream. The method further includes adjusting operating parameters corresponding to the gas processing system based on the determined amount of acid gases absorbed by the solvent stream within each co-current contacting system.

25 **[0015]** In various embodiments, the acid gases include H₂S and CO₂, and the method further includes measuring the amount of H₂S absorbed by the solvent stream within each co-current contacting system via an H₂S analyzer positioned downstream of each co-current contacting system, and determining the amount of CO₂ absorbed by the solvent stream within each co-current contacting system by subtracting the amount of H₂S absorbed by the solvent stream from the
30 amount of acid gases absorbed by the solvent stream for each co-current contacting system.

Moreover, in various embodiments, the method includes: (1) measuring both the liquid inlet temperature and the gas inlet temperature upstream of each co-current contacting system; and (2) measuring the gas outlet temperature downstream of each co-current contacting system, while assuming that the liquid outlet temperature for each co-current contacting system is approximately the same as the corresponding gas outlet temperature.

[0016] In some embodiments, adjusting the operating parameters corresponding to the gas processing system includes dynamically adjusting the reboiler duty of the regenerator based on fluctuations in the amount of acid gases absorbed by the solvent stream within each co-current contacting system. Additionally or alternatively, in some embodiments, adjusting the operating parameters corresponding to the gas processing system includes dynamically adjusting the solvent flow rate and/or the solvent temperature based on fluctuations in the amount of acid gases absorbed by the solvent stream within each co-current contacting system. In such embodiments, the method may include dynamically adjusting the solvent flow rate and/or the solvent temperature to provide for enhanced H₂S removal from the sour feed gas stream.

[0017] In some embodiments, the method includes adjusting operating parameters corresponding a downstream process based on the determined amount of acid gases absorbed by the solvent stream within each co-current contacting system of the gas processing system. In such embodiments, the downstream process may include a downstream acid gas enrichment process, and adjusting the operating parameters may include increasing the solvent flow rate corresponding to the downstream acid gas enrichment process in response to fluctuations in the amount of acid gases absorbed by the solvent stream within each co-current contacting system of the gas processing system.

[0018] In various embodiments, adjusting the operating parameters corresponding to the gas processing system includes monitoring the amount of acid gases absorbed by the solvent stream within each co-current contacting system to determine whether a total amount of absorbed acid gases exceeds a predetermined acid gas loading limit and, if the total amount of absorbed acid gases exceeds the predetermined acid gas loading limit, increasing the solvent flow rate to avoid operating at conditions that are favorable for corrosion.

[0019] Furthermore, in some embodiments, the method includes adjusting the configuration of the gas processing system based on the amount of acid gases absorbed by the solvent stream

within each co-current contacting system. In such embodiments, this may include adding at least one additional co-current contacting system to optimize an operation of the gas processing system.

[0020] Another embodiment described herein provides a computing system including a processor and a non-transitory, computer-readable storage medium. The non-transitory, computer-readable storage medium includes code configured to direct the processor to instruct a controller of a gas processing system to: (1) contact a sour feed gas stream including acid gases with a solvent stream within co-current contacting systems of the gas processing system to generate a sweetened gas stream and a rich solvent stream including absorbed acid gases; (2) remove the absorbed acid gases from the rich solvent stream within a regenerator of the gas processing system to regenerate the solvent stream; (3) measure a gas flow rate for the sour feed gas stream and a solvent flow rate for the solvent stream via corresponding flow meters within the gas processing system; (4) measure at least one of a liquid inlet temperature or a gas inlet temperature for each co-current contacting system via a corresponding temperature sensor positioned upstream of each co-current contacting system; and (5) measure at least one of a liquid outlet temperature or a gas outlet temperature for each co-current contacting system via a corresponding temperature sensor positioned downstream of each co-current contacting system. The non-transitory, computer-readable storage medium also includes code configured to direct the processor to determine an amount of acid gases absorbed by the solvent stream within each co-current contacting system based on the gas flow rate, the solvent flow rate, the at least one of the liquid inlet temperature or the gas inlet temperature, and the at least one of the liquid outlet temperature or the gas outlet temperature, in combination with the heat of reaction between the acid gases and the solvent stream. The non-transitory, computer-readable storage medium further includes code configured to direct the processor to instruct the controller to adjust operating parameters corresponding to the gas processing system based on the determined amount of acid gases absorbed by the solvent stream within each co-current contacting system.

[0021] In various embodiments, the acid gases comprise H_2S and CO_2 , and the non-transitory, computer-readable storage medium includes code configured to direct the processor to instruct the controller to measure the amount of H_2S absorbed by the solvent stream within each co-current contacting system via an H_2S analyzer positioned downstream of each co-current contacting system. In such embodiments, the computer-readable storage medium also includes code

configured to direct the processor to determine the amount of CO₂ absorbed by the solvent stream within each co-current contacting system by subtracting the amount of H₂S absorbed by the solvent stream from the amount of acid gases absorbed by the solvent stream for each co-current contacting system.

5 **[0022]** In some embodiments, the non-transitory, computer-readable storage medium includes code configured to direct the processor to instruct the controller to adjust the operating parameters corresponding to the gas processing system by dynamically adjusting the reboiler duty of the regenerator based on fluctuations in the amount of acid gases absorbed by the solvent stream within each co-current contacting system. Additionally or alternatively, in some embodiments, the non-
10 transitory, computer-readable storage medium includes code configured to direct the processor to instruct the controller to adjust the operating parameters corresponding to the gas processing system by dynamically adjusting the solvent flow rate and/or the solvent temperature based on fluctuations in the amount of acid gases absorbed by the solvent stream within each co-current contacting system. In such embodiments, the non-transitory, computer-readable storage medium
15 may include code configured to direct the processor to instruct the controller to dynamically adjust the solvent flow rate and/or the solvent temperature to provide for enhanced H₂S removal from the sour feed gas stream.

[0023] In some embodiments, the non-transitory, computer-readable storage medium includes code configured to direct the processor to instruct a controller corresponding to a downstream
20 process to adjust operating parameters corresponding to the downstream process based on the determined amount of acid gases absorbed by the solvent stream within each co-current contacting system of the gas processing system. In such embodiments, the downstream process may include a downstream acid gas enrichment process, and the non-transitory, computer-readable storage medium may include code configured to direct the processor to instruct the controller
25 corresponding to the downstream acid gas enrichment process to increase the solvent flow rate corresponding to the downstream acid gas enrichment process in response to fluctuations in the amount of acid gases absorbed by the solvent stream within each co-current contacting system of the gas processing system.

[0024] In some embodiments, the non-transitory, computer-readable storage medium includes
30 code configured to direct the processor to instruct the controller to adjust the operating parameters

corresponding to the gas processing system by monitoring the amount of acid gases absorbed by the solvent stream within each co-current contacting system to determine whether a total amount of absorbed acid gases exceeds a predetermined acid gas loading limit and, if the total amount of absorbed acid gases exceeds the predetermined acid gas loading limit, increasing the solvent flow rate to avoid operating at conditions that are favorable for corrosion. Furthermore, in some
5 embodiments, the non-transitory, computer-readable storage medium includes code configured to direct the processor to provide instructions relating to an alternative configuration of the gas processing system that will optimize the operation of the gas processing system.

[0025] Another embodiment provides a non-transitory, computer-readable storage medium,
10 including program instructions that are executable by a processor to cause the processor to instruct a controller of a gas processing system to: (1) contact a sour feed gas stream including acid gases with a solvent stream within co-current contacting systems of the gas processing system to generate a sweetened gas stream and a rich solvent stream including absorbed acid gases; (2) remove the absorbed acid gases from the rich solvent stream within a regenerator of the gas
15 processing system to regenerate the solvent stream; (3) measure a gas flow rate for the sour feed gas stream and a solvent flow rate for the solvent stream via corresponding flow meters within the gas processing system; (4) measure at least one of a liquid inlet temperature or a gas inlet temperature for each co-current contacting system via a corresponding temperature sensor positioned upstream of each co-current contacting system; and (5) measure at least one of a liquid
20 outlet temperature or a gas outlet temperature for each co-current contacting system via a corresponding temperature sensor positioned downstream of each co-current contacting system. The non-transitory, computer-readable storage medium also includes program instructions that are executable by the processor to cause the processor to determine an amount of acid gases absorbed by the solvent stream within each co-current contacting system based on the gas flow rate, the
25 solvent flow rate, the at least one of the liquid inlet temperature or the gas inlet temperature, and the at least one of the liquid outlet temperature or the gas outlet temperature, in combination with the heat of reaction between the acid gases and the solvent stream. The non-transitory, computer-readable storage medium further includes program instructions that are executable by the processor to cause the processor to instruct the controller to adjust operating parameters corresponding to the

gas processing system based on the determined amount of acid gases absorbed by the solvent stream within each co-current contacting system.

DESCRIPTION OF THE DRAWINGS

5 [0026] Advantages of the present techniques may become apparent upon reviewing the following detailed description and drawings of non-limiting examples in which:

[0027] FIG. 1A is a graph showing the results of experimental testing for calculating the expected outlet temperature for given acid gas loading conditions without considering the heat of reaction;

10 [0028] FIG. 1B is a graph showing the results of experimental testing for calculating the expected outlet temperature for given acid gas loading conditions while considering the heat of reaction according to embodiments described herein;

[0029] FIG. 2 is a simplified process flow diagram of an exemplary gas processing system for which the acid gas loading control techniques described herein may be implemented;

15 [0030] FIG. 3 is a more detailed process flow diagram of another exemplary gas processing system for which the acid gas loading control techniques described herein may be implemented;

[0031] FIG. 4 is a schematic view of an exemplary co-current contacting system that can be used to provide a gas processing system with a co-current flow scheme according to embodiments described herein;

20 [0032] FIG. 5 is a process flow diagram of a method for controlling acid gas loading within a gas processing system;

[0033] FIG. 6 is a block diagram of an exemplary cluster computing system that may be utilized to implement the acid gas loading control techniques described herein; and

25 [0034] FIG. 7 is a block diagram of an exemplary non-transitory, computer-readable storage medium that may be used for the storage of data and modules of program instructions for implementing the acid gas loading control techniques described herein.

[0035] It should be noted that the figures are merely examples of the present techniques and are not intended to impose limitations on the scope of the present techniques. Further, the figures are generally not drawn to scale, but are drafted for purposes of convenience and clarity in
30 illustrating various aspects of the techniques.

DETAILED DESCRIPTION

[0036] In the following detailed description section, the specific examples of the present techniques are described in connection with preferred embodiments. However, to the extent that the following description is specific to a particular embodiment or a particular use of the present techniques, this is intended to be for example purposes only and simply provides a description of the embodiments. Accordingly, the techniques are not limited to the specific embodiments described below, but rather, include all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

[0037] At the outset, and for ease of reference, certain terms used in this application and their meanings as used in this context are set forth. To the extent a term used herein is not defined below, it should be given the broadest definition persons in the pertinent art have given that term as reflected in at least one printed publication or issued patent. Further, the present techniques are not limited by the usage of the terms shown below, as all equivalents, synonyms, new developments, and terms or techniques that serve the same or a similar purpose are considered to be within the scope of the present claims.

[0038] As used herein, the terms “a” and “an” mean one or more when applied to any embodiment described herein. The use of “a” and “an” does not limit the meaning to a single feature unless such a limit is specifically stated.

[0039] The terms “about” and “around” mean a relative amount of a material or characteristic that is sufficient to provide the intended effect. The exact degree of deviation allowable in some cases may depend on the specific context, e.g., $\pm 1\%$, $\pm 5\%$, $\pm 10\%$, $\pm 15\%$, etc. It should be understood by those of skill in the art that these terms are intended to allow a description of certain features described and claimed without restricting the scope of these features to the precise numerical ranges provided. Accordingly, these terms should be interpreted as indicating that insubstantial or inconsequential modifications or alterations of the subject matter described are considered to be within the scope of the disclosure.

[0040] The term “acid gas” refers to any gas that dissolves in water, producing an acidic solution. Non-limiting examples of acid gases include hydrogen sulfide (H_2S), carbon dioxide

(CO₂), sulfur dioxide (SO₂), carbon disulfide (CS₂), carbonyl sulfide (COS), mercaptans, or mixtures thereof.

[0041] The term “and/or” placed between a first entity and a second entity means one of (1) the first entity, (2) the second entity, and (3) the first entity and the second entity. Multiple entities listed with “and/or” should be construed in the same manner, i.e., “one or more” of the entities so conjoined. Other entities may optionally be present other than the entities specifically identified by the “and/or” clause, whether related or unrelated to those entities specifically identified. Thus, as a non-limiting example, a reference to “A and/or B,” when used in conjunction with open-ended language such as “including,” may refer, in one embodiment, to A only (optionally including entities other than B); in another embodiment, to B only (optionally including entities other than A); in yet another embodiment, to both A and B (optionally including other entities). These entities may refer to elements, actions, structures, steps, operations, values, and the like.

[0042] The phrase “at least one,” in reference to a list of one or more entities, should be understood to mean at least one entity selected from any one or more of the entities in the list of entities, but not necessarily including at least one of each and every entity specifically listed within the list of entities, and not excluding any combinations of entities in the list of entities. This definition also allows that entities may optionally be present other than the entities specifically identified within the list of entities to which the phrase “at least one” refers, whether related or unrelated to those entities specifically identified. Thus, as a non-limiting example, “at least one of A and B” (or, equivalently, “at least one of A or B,” or, equivalently, “at least one of A and/or B”) may refer, in one embodiment, to at least one, optionally including more than one, A, with no B present (and optionally including entities other than B); in another embodiment, to at least one, optionally including more than one, B, with no A present (and optionally including entities other than A); in yet another embodiment, to at least one, optionally including more than one, A, and at least one, optionally including more than one, B (and optionally including other entities). In other words, the phrases “at least one,” “one or more,” and “and/or” are open-ended expressions that are both conjunctive and disjunctive in operation. For example, each of the expressions “at least one of A, B, and C,” “at least one of A, B, or C,” “one or more of A, B, and C,” “one or more of A, B, or C,” and “A, B, and/or C” may

mean A alone, B alone, C alone, A and B together, A and C together, B and C together, A, B, and C together, and optionally any of the above in combination with at least one other entity.

[0043] As used herein, the term “co-current contactor” refers to a vessel that receives a stream of gas and a separate stream of solvent in such a manner that the gas stream and the solvent stream
5 contact one another while flowing in generally the same directions within the contactor.

[0044] The term “co-currently” refers to the internal arrangement of process streams within a unit operation that can be divided into several sub-sections by which the process streams flow in the same direction.

[0045] As used herein, the term “configured” means that the element, component, or other
10 subject matter is designed and/or intended to perform a given function. Thus, the use of the term “configured” should not be construed to mean that a given element, component, or other subject matter is simply “capable of” performing a given function but that the element, component, and/or other subject matter is specifically selected, created, implemented, utilized, and/or designed for the purpose of performing the function.

[0046] As used herein, the terms “example,” “exemplary,” and “embodiment,” when used with
15 reference to one or more components, features, structures, or methods according to the present techniques, are intended to convey that the described component, feature, structure, or method is an illustrative, non-exclusive example of components, features, structures, or methods according to the present techniques. Thus, the described component, feature, structure, or method is not
20 intended to be limiting, required, or exclusive/exhaustive; and other components, features, structures, or methods, including structurally and/or functionally similar and/or equivalent components, features, structures, or methods, are also within the scope of the present techniques.

[0047] The term “fluid” refers to gases, liquids, and combinations of gases and liquids, as well as to combinations of gases and solids, and combinations of liquids and solids.

[0048] The term “gas” is used interchangeably with “vapor,” and is defined as a substance or
25 mixture of substances in the gaseous state as distinguished from the liquid or solid state. Likewise, the term “liquid” means a substance or mixture of substances in the liquid state as distinguished from the gas or solid state.

[0049] As used herein, the term “hydrocarbon” refers to an organic compound that primarily
30 includes the elements hydrogen and carbon, although nitrogen, sulfur, oxygen, metals, or any

number of other elements may be present in small amounts. As used herein, the term “hydrocarbon” generally refers to components found in natural gas, oil, or chemical processing facilities. Moreover, the term “hydrocarbon” may refer to components found in raw natural gas, such as CH₄, C₂H₆, C₃ isomers, C₄ isomers, benzene, and the like.

5 **[0050]** With respect to fluid processing equipment, the term “in series” means that two or more devices are placed along a flowline such that a fluid stream (such as a gas stream that is undergoing a purification process) moves from one item of equipment to the next while maintaining flow in a substantially constant downstream direction. Conversely, the term “in parallel” means that two or more devices are arranged such that a fluid stream (such as a gas stream that is undergoing a
10 purification process and/or a liquid solvent stream that is aiding in the purification process) is divided among the two or more devices, with a portion of the fluid stream flowing through each of the devices.

[0051] The term “natural gas” refers to a multi-component gas obtained from a crude oil well or from a subterranean gas-bearing formation. The composition and pressure of natural gas can
15 vary significantly. A typical natural gas stream contains methane (CH₄) as a major component, i.e., greater than 50 mole percent (mol. %) of the natural gas stream. The natural gas stream can also contain ethane (C₂H₆), higher molecular weight hydrocarbons (e.g., C₃-C₂₀ hydrocarbons), acid gases (e.g., carbon dioxide and hydrogen sulfide), or any combinations thereof. The natural gas can also contain minor amounts of contaminants such as water, nitrogen, iron sulfide, wax,
20 crude oil, or any combinations thereof.

[0052] As used herein, the term “purification” refers to separation processes by which impurities that may cause problems to downstream processes are removed.

[0053] The term “solvent” refers to a substance capable at least in part of dissolving or dispersing other substances, such as to provide or form a solution. The solvent may be polar,
25 nonpolar, neutral, protic, aprotic, or the like. The solvent may include any suitable element, molecule, or compound, such as methanol, ethanol, propanol, glycols, ethers, ketones, other alcohols, amines, salt solutions, or the like. The solvent may include physical solvents, chemical solvents, or the like. The solvent may operate by any suitable mechanism, such as physical absorption, chemical absorption, chemisorption, physisorption, adsorption, pressure swing
30 adsorption, temperature swing adsorption, or the like. Specific solvents that are useful for acid gas

absorption include, but are not limited to, monoethanolamine (MEA), 2(2-aminoethoxy) ethanol [Diglycolamine® (DGA)], diethanolamine (DEA), diisopropanolamine (DIPA), methyldiethanolamine (MDEA), triethyleneamine, FLEXSORB® SE, 2-amino-2-methyl-1-propanol (AMP), or formulated amines such as FLEXSORB® SE PLUS, the UCARSOL™ family
5 of products, or formulated MDEA solutions.

[0054] As used herein, the term “solvent flow rate” refers to the rate at which a particular solvent stream is flowing into one or more co-current contacting systems, while the term “solvent circulation rate” refers to the rate at which the entire solvent stream is flowing from the co-current contacting systems to the regenerator and back again. Thus, for embodiments in which the co-current contacting systems are configured in series such that the solvent stream is flowing
10 sequentially through each co-current contacting system, the solvent flow rate and the solvent circulation rate may be approximately equivalent. However, for embodiments in which the co-current contacting systems are configured in parallel such that the solvent stream is split between the co-current contacting systems, the solvent flow rate and the solvent circulation rate may not be
15 equivalent, and the solvent flow rate may vary for each co-current contacting system.

[0055] Similarly, the term “gas flow rate” refers to the rate at which a particular gas stream is flowing into one or more co-current contacting systems. For embodiments in which the co-current contacting systems are configured in series such that the gas stream is flowing sequentially through each co-current contacting system, the gas flow rate may remain substantially constant as it flows
20 through the co-current contacting systems. However, for embodiments in which the co-current contacting systems are configured in parallel such that the gas stream is split between the co-current contacting systems, the gas flow rate may not remain substantially constant but, rather, may vary for each co-current contacting system.

[0056] The term “substantial”, when used in reference to a quantity or amount of a material, or a specific characteristic thereof, refers to an amount that is sufficient to provide an effect that
25 the material or characteristic was intended to provide. The exact degree of deviation allowable may depend, in some cases, on the specific context.

[0057] The terms “well” and “wellbore” refer to holes drilled vertically, at least in part, and may also refer to holes drilled with deviated, highly deviated, and/or lateral sections. The term

also includes the wellhead equipment, surface casing string, intermediate casing string(s), production casing string, and the like, typically associated with hydrocarbon wells.

[0058] Certain aspects and features are described herein using a set of numerical upper limits and a set of numerical lower limits. It should be appreciated that ranges from any lower limit to any upper limit are contemplated unless otherwise indicated. All numerical values are “about” or “approximately” the indicated value, and account for experimental errors and variations that would be expected by a person having ordinary skill in the art.

[0059] Overview of Technical Problem

[0060] As described herein, current acid gas removal processes typically remove acid gases from a raw natural gas stream using chemical solvents. Such chemical solvents often include amines, such as monoethanol amine (MEA), diethanol amine (DEA), and/or methyl diethanol amine (MDEA). These amine-based solvents rely on chemical reactions between the solvent and the acid gases, e.g., the H_2S and CO_2 , within the natural gas stream. Moreover, in general, the chemical reaction of H_2S with the amine is inherently very fast and is often considered instantaneous with respect to diffusion and other mass transfer limitations. However, the reaction of CO_2 is somewhat slower. Therefore, the difference in these reaction rates can be effectively utilized to selectively remove H_2S from the natural gas stream.

[0061] Furthermore, the chemical reactions between the solvent and the acid gases are also exothermic. In particular, the series of reactions that occur during H_2S absorption release around 30-40 kilojoules per mole of H_2S (kJ/mol- H_2S), while the series of reactions that occur during CO_2 absorption release around 50-60 kJ/mol- CO_2 . This heat release is significant enough to impact the temperature of the process fluids. For example, in a conventional acid gas removal process including a counter-current flow scheme, a temperature bulge is often observed within the contacting portion of the absorber. The lean solvent may enter the top of the absorber at a temperature of around 45 °C, and the gas may enter the bottom of the absorber at a temperature of around 40 °C. However, due to the exothermic reactions occurring within the absorber, it is not uncommon to observe a temperature of around 80-90 °C in the center of the column, with the outlet temperatures of the fluids then approaching the inlet temperatures due to cooling from the counter-current contact with the entering fluids.

[0062] Improved acid gas removal processes including co-current flow schemes have been developed. In particular, such improved processes include one or more co-current contacting systems, where each co-current contacting system acts as an individual absorption stage for sequentially lowering the concentration of the acid gases within the natural gas stream. Each co-current contacting system includes a co-current contactor that provides for the absorption of the acid gases from the natural gas stream into a solvent stream, as well as a separator that separates the solvent stream with the absorbed acid gases from the natural gas stream, producing a sweetened natural gas stream. Moreover, such improved acid gas removal processes including compact, co-current contacting systems are particularly well-suited for selective H₂S removal as compared to conventional acid gas removal processes including large absorbers. Specifically, the co-current contacting systems allow for the minimization of the gas and liquid contact times and, thus, the utilization of the relatively fast reaction rate of H₂S with the solvent to provide enhanced H₂S removal with little to no CO₂ removal. More details relating to this improved acid gas removal process and the associated co-current contacting systems are provided with respect to **FIGS. 2-4**.

[0063] In general, one of the most important process parameters to monitor and control during acid gas removal processes is the amount of acid gas that is being picked up by solvent. This is referred to as the “acid gas loading”, and it is generally provided in units of moles of acid gas per mole of amine (mol-acid gas/mol-amine). However, in operation, it can be challenging to determine the total amount of acid gas absorbed during the process. Specifically, while the amount of H₂S absorbed can be determined using H₂S analyzers, such analyzers are relatively expensive and difficult to maintain. Moreover, it is more difficult to determine the amount of CO₂ absorbed due to small differences in gas phase concentration. However, CO₂ often makes up a large percentage of the absorbed acid gases. For example, given a 10 million standard cubic feet per day (MMscfd) gas with 2.5% CO₂ and 200 parts per million (ppm) H₂S, the H₂S may be removed down to a concentration of 4 ppm, meaning that $100 \times (0.0002 - 0.000004) = 0.0196$ MMscfd of H₂S is absorbed. In addition, a CO₂ slip of, for example, 95% may be achieved, meaning that the outlet concentration of CO₂ is $2.5\% \times (95\%) = 2.25\%$. Thus, the overall CO₂ concentration may only be reduced by around 0.25%. This small reduction in CO₂ concentration is difficult to measure using a gas phase analyzer. However, 0.25% of CO₂ equals 0.25 MMscfd of CO₂, which is greater than 10 times the amount of H₂S absorbed. Accordingly, the acid gas that is the most difficult to

measure is often the dominant component controlling the acid gas loading conditions within the gas processing system.

[0064] Laboratory methods for measuring acid gas loading have been developed. However, such laboratory methods are difficult to perform on rich samples. The measurements require a physical sample from the process, which can be labor-intensive and hazardous to obtain, particularly in the presence of H₂S. In addition, the acid gases are prone to flashing and degradation after collection, thus reducing the accuracy of the resulting measurements. Furthermore, while gas phase analyzers can be utilized, as discussed above, such analyzers are expensive and difficult to maintain. Moreover, such gas phase analyzers are typically placed on top of the regenerator overhead within the gas processing system. Therefore, the measurements obtained from such analyzers do not provide an indication of individual stage performance.

[0065] Technical Solution Provided by Improved Acid Gas Loading Control Techniques Described Herein

[0066] Embodiments described herein provide for the improved control of acid gas loading within gas processing systems that include co-current flow schemes. More specifically, embodiments described herein provides methods for utilizing the heat of reaction between the solvent stream and the natural gas stream as they contact each other within the co-current contacting systems to determine the amount of acid gases absorbed during each stage of the acid gas removal process. This is accomplished by leveraging the unique characteristics of the co-current contacting systems to correlate easily-measured process variables with the acid gas loading conditions. In particular, according to embodiments described herein, the inlet and outlet temperatures of each stage (i.e., each co-current contacting system) are measured, and the measured temperatures are then used, in combination with the flow rates for the solvent stream and the natural gas stream, to solve heat balance equations for the total mass of acid gas that is absorbed within each stage. In this manner, the exothermic nature of the process is utilized to estimate the acid gas loading on a stage-by-stage basis.

[0067] In various embodiments, the resulting estimate for the acid gas loading incorporates both the heat capacities of the vapor and liquid phases and the heat of reaction of the absorbed components using a heat balance for the mixed system, as shown in Equations (3) and (4).

$$Q_{out} = Q_{in} + \sum_i m_i \times \Delta H_{rxn,i} \quad (3)$$

$$(m_{out} \times c_{p,out} \times T_{out}) = (m_v \times c_{p,v} \times T_{v,in}) + (m_l \times c_{p,l} \times T_{l,in}) \\ + (m_{H_2S} \times \Delta H_{H_2S}) + (m_{CO_2} \times \Delta H_{CO_2}) \quad (4)$$

5

[0068] In Equations (3) and (4), Q refers to the heat in joules per hour (J/hr) or joules per second (J/sec); ΔH refers to the change in enthalpy (or heat of reaction) in joules/kilogram (J/kg); c_p refers to the specific heat in joules/kilogram-Kelvin (J/kgK); and m refers to the mass in kilograms per hour (kg/hr) or kilograms per second (kg/sec). The subscript “v” refers to the vapor or gas phase (i.e., the natural gas stream), while the subscript “l” refers to the liquid phase (i.e., the solvent stream). Moreover, the subscript “in” refers to a liquid or vapor phase entering a co-current contacting system, while the subscript “out” refers to a liquid or vapor phase exiting a co-current contacting system.

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[0069] For embodiments in which the solvent stream includes tertiary amines, such as MDEA, Equation (4) can be simplified further. Specifically, because the heats of reaction of H_2S and CO_2 with tertiary amines are similar, and because CO_2 is typically the dominant species, the heats of reaction can be combined into a single average value approximated by the heat of reaction with CO_2 , as shown in Equation (5).

15

$$(m_{out} \times c_{p,out} \times T_{out}) = (m_v \times c_{p,v} \times T_{v,in}) + (m_l \times c_{p,l} \times T_{l,in}) \\ + (m_{H_2S} + m_{CO_2}) \times \overline{\Delta H_{rxn}} \quad (5)$$

20

By rearranging Equation (5), an equation for calculating the total acid gas pickup is obtained, as shown in Equation (6).

25

$$(m_{H_2S} + m_{CO_2}) = \frac{(m_{out} \times c_{p,out} \times T_{out}) - (m_v \times c_{p,v} \times T_{v,in}) + (m_l \times c_{p,l} \times T_{l,in})}{\overline{\Delta H_{rxn}}} \quad (6)$$

Moreover, by calculating the outlet mass rate and the outlet heat capacity as an average of the inlet, Equation (6) can be further simplified, as shown in Equation (7).

30

$$(m_{\text{H}_2\text{S}} + m_{\text{CO}_2}) = \frac{m_v \times c_{p,v} \times (T_{\text{out}} - T_{v,\text{in}}) + m_l \times c_{p,l} \times (T_{\text{out}} - T_{l,\text{in}})}{\Delta H_{\text{rxn}}} \quad (7)$$

[0070] It has been demonstrated through testing that Equations (3)-(7) adequately represent the acid gas removal process within co-current contacting systems. Specifically, **FIG. 1A** is a graph **100** showing the results of experimental testing for calculating the expected outlet temperature for given acid gas loading conditions without considering the heat of reaction. Conversely, **FIG. 1B** is a graph **102** showing the results of experimental testing for calculating the expected outlet temperature for given acid gas loading conditions while considering the heat of reaction according to embodiments described herein. In shown in **FIG. 1B**, when the heat of reaction is considered according to Equations (3)-(7), 85% of the data is predicted within 2 °F. Accordingly, heat balance equations relying on the exothermic nature of the chemical reactions between the H₂S and CO₂ and the solvent can be reliably used, in conjunction with the heat balance equations described above, to determine the total mass of H₂S and CO₂ absorbed by the solvent during the acid gas removal process.

[0071] Moreover, while Equation (7) provides the total mass of absorbed H₂S and CO₂, in some embodiments, it is desirable to determine separate loading conditions for H₂S and CO₂. In such embodiments, a gas phase analyzer (i.e., an H₂S analyzer) may be used to determine the amount of H₂S absorbed. It is then trivial to subtract the amount of H₂S from the total acid gas loading to derive the amount of CO₂ absorbed.

[0072] According to embodiments described herein, the measured acid gas loading conditions are then used to optimize the overall performance of the gas processing system. In particular, the acid gas loading conditions can be continuously (or periodically) monitored and used to determine online process adjustments that will increase the efficiency of the gas processing system. For example, in various embodiments, the solvent temperature, overall solvent circulation rate, solvent flow rate (which may be equivalent to the solvent circulation rate or may vary for each co-current contacting system, depending on the system configuration), reboiler duty of the regenerator, and/or number of contacting stages may be adjusted as appropriate based on the determined acid gas loading conditions, as described further herein. Moreover, the acid gas loading conditions can also be used as a feedforward control for one or more downstream operations, such as, for example, a downstream acid gas enrichment process.

[0073] Notably, the techniques described herein are specifically adapted to gas processing systems including co-current flow schemes, since the outlet streams for gas processing systems including counter-current flow schemes are continuously cooled within the absorbers, thus convoluting the analysis of the heat contributions. Moreover, while various configurations of gas processing systems including co-current flow schemes can be envisioned by one of skill in the art, specific details relating to exemplary implementations of such gas processing systems are described with respect to **FIGS. 2-4**. Furthermore, while the techniques described herein are particularly well-suited for selective H₂S removal processes, one of skill in the art will appreciate that such techniques can also be applied to other types of absorption processes.

[0074] Exemplary Gas Processing Systems for Implementing Techniques Described Herein

[0075] **FIG. 2** is a simplified process flow diagram of an exemplary gas processing system **200** for which the acid gas loading control techniques described herein may be implemented. The gas processing system **200** includes a number of co-current contacting systems **202A-C** that are used for the removal of acid gas components, such as H₂S and CO₂, from a sour feed gas stream **204**. In particular, the exemplary gas processing system **200** shown in **FIG. 2** includes a first co-current contacting system **202A**, a second co-current contacting system **202B**, and a third co-current contacting system **202C** connected in series.

[0076] In operation, the sour feed gas stream **204** is flowed into the first co-current contacting system **202A**. The first co-current contacting system **202A** generates a first partially-sweetened gas stream **206A**, which is flowed from the first co-current contacting system **202A** to the second co-current contacting system **202B**. The second co-current contacting system **202B** generates a second partially-sweetened gas stream **206B**, which is flowed from the second co-current contacting system **202B** to the third co-current contacting system **202C**. The third co-current contacting system **202C** then generates a final sweetened gas stream **208**.

[0077] Each of the first, second, and third co-current contacting systems **202A-C** also generates a respective rich solvent stream **210A-C**. According to the embodiment shown in **FIG. 2**, the third rich solvent stream **210C** is directed back to the second co-current contacting system **202B**, and the second rich solvent stream **210B** is directed back to the first co-current contacting system **202A**. In addition, the first rich solvent stream **210A** is returned to a regenerator **212**.

[0078] The regenerator **212** removes absorbed acid gases and other impurities from the first rich solvent stream **210A**, producing a lean solvent stream **214**. The lean solvent stream **214** is then directed through a pump **216** and a heat exchanger **218**, which control the flow rate and temperature, respectively, of the lean solvent stream **214** as it is recycled back into the third co-current contacting system **202C**. For example, in some embodiments, the heat exchanger **218** reduces the temperature of the lean solvent stream **214** to around 10 °F warmer than the temperature of the sour feed gas stream **204**. This may enable the lean solvent stream **214** to absorb a higher concentration of acid gases from the second partially-sweetened gas stream **206B**. In various embodiments, the resulting sweetened gas stream **210** includes a low concentration of acid gases, such as, for example, less than 4 ppm H₂S and less than 2-3 vol. % CO₂.

[0079] According to embodiments described herein, the gas processing system **200** also includes temperature sensors **220A-G** that are configured to measure the inlet and/or outlet temperatures of various gas and liquid solvent streams that are entering and/or exiting the co-current contacting systems **202A-C**. Specifically, according to the embodiment shown in **FIG. 2**, a first and second temperature sensor **220A** and **220B** measure the inlet temperatures of the sour feed gas stream **204** and the second rich solvent stream **210B**, respectively, as the streams flow into the first co-current contacting system **202A**. A third temperature sensor **220C** measures the outlet temperature of the first partially-sweetened gas stream **206A** exiting the first co-current contacting system **202A**, which is substantially equal to the inlet temperature of the first partially-sweetened gas stream **206A** as it flows into the second co-current contacting system **202B**. In addition, a fourth temperature sensor **220D** measures the inlet temperature of the third rich solvent stream **210C** as it flows into the second co-current contacting system **202B**. Furthermore, a fifth temperature sensor **220E** measures the outlet temperature of the second partially-sweetened gas stream **206B** exiting the second co-current contacting system **202B**, which is substantially equal to the inlet temperature of the second partially-sweetened gas stream **206B** as it flows into the third co-current contacting system **202C**. A sixth temperature sensor **220F** also measures the inlet temperature of the lean solvent stream **214** as it flows into the third co-current contacting system **202C**, while a seventh temperature sensor **220G** measures the outlet temperature of the final sweetened gas stream **208**.

[0080] Moreover, it will be appreciated by one of skill in the art that any number of additional or alternative temperature sensors not shown in **FIG. 2** may also be included within the gas processing system described herein. For example, while the outlet temperatures of the gas and liquid solvent streams are assumed to be approximately the same according to the embodiment shown in **FIG. 2**, in other embodiments, additional temperature sensors may be included to measure the outlet temperatures of the liquid solvent streams separately from the outlet temperatures of the corresponding gas streams. Moreover, while the inlet temperatures of the gas and liquid solvent streams are measured separately according to the embodiment shown in **FIG. 2**, in other embodiments, it may be assumed that the inlet temperatures of the corresponding gas and liquid solvent streams are approximately the same and, thus, fewer temperature sensors may be included within the gas processing system **200**.

[0081] Furthermore, according to embodiments described herein, the gas processing system **200** includes flow meters **222A** and **222B** that are configured to measure the inlet flow rate of the sour feed gas stream **204** and the lean solvent stream **214**, respectively, flowing into the co-current contacting systems **202A** and **202C**. As will be appreciated by one of skill in the art, the flow rates for the gas and solvent streams are typically measured within conventional gas processing systems. Therefore, measuring the flow rates will not result in any additional capital or operating expenditures for the overall gas processing system **200**. In addition, one of skill in the art will appreciate that any suitable type of flow rate sensor can be used to measure the gas and liquid flow rates, and such flow rate sensors can be positioned in any suitable location within the gas processing system **200**, depending on the details of the specific implementation.

[0082] The temperature and flow rate measurements recorded by the temperature sensors **220A-G** and flow meters **222A-B**, respectively, are then sent to a controller **224** of the gas processing system **200** via wired or wireless communication methods, as indicated by dotted line **226** in **FIG. 2**. The controller **224** is configured to utilize such information to control the operation of the equipment within the gas processing system **200**. Specifically, the controller **224** is configured to send information to, and receive instructions from, a computing system (not shown) via wired or wireless communication methods. In various embodiments, the computing system is controlled by an operator of the gas processing system **200**. Moreover, details relating to exemplary embodiments of the computing system are described with respect to **FIGS. 6** and **7**.

[0083] According to embodiments described herein, the computing system, in conjunction with the controller **224**, is configured to control the acid gas loading conditions within the gas processing system **200** according to the techniques described herein. Specifically, the computing system uses the recorded flow rates and inlet/outlet temperatures received from the controller **224** to calculate the total acid gas pickup corresponding to each stage of the acid gas removal process (i.e., corresponding to each co-current contacting system **202A-C**) using the heat balance for the mixed system, as described with respect to Equations (3)-(7). In various embodiments, this allows for the determination of the total amount of H₂S and CO₂ that was absorbed by the solvent at each stage of the process. Moreover, for embodiments in which it is desirable to separately determine the amount of H₂S and the amount of CO₂ that was absorbed by the solvent at each stage of the process, H₂S analyzers **228A-D** may optionally be provided upstream and downstream of each co-current contacting system **202A-C**. It is then trivial to subtract the amount of absorbed H₂S, as determined by the H₂S analyzers **228A-D**, from the total acid gas loading to derive the amount of CO₂ absorbed at each stage of the process.

[0084] In various embodiments, the computing system, in conjunction with the controller **224**, utilizes the calculated acid gas loading conditions to determine appropriate operating parameter adjustments that will optimize the acid gas removal process. For example, the computing system may direct the controller **224** to adjust the operation of the regenerator **212**, the pump **216** (and/or other flow control devices), and/or the heat exchanger **218** (and/or other temperature control devices), as indicated by dotted lines **230**.

[0085] In some embodiments, the controller **224** adjusts the reboiler duty of the regenerator **212** to improve the energy efficiency of the process. In general, the reboiler duty of the regenerator is a function of the solvent circulation rate and the amount of absorbed acid gases, with the absorbed acid gases contributing to as much as one third of the overall heat duty. The reboiler duty is commonly controlled by a fixed ratio with the solvent circulation rate, which assumes constant acid gas loading conditions. However, according to embodiments described herein, the measured acid gas loading conditions can be used to correct the reboiler duty to account for any increases and/or decreases in energy that are required to regenerate the solvent stream. In this manner, embodiments described herein provide for the dynamic adjustment of the regeneration process based on fluctuations in the acid gas loading conditions caused by, for example, feed gas

composition changes and/or operating temperature changes. This provides the significant advantage of reducing the overall energy consumption and, thus, the operating costs for the gas processing system **200**.

[0086] In some embodiments, the controller **224** adjusts the solvent flow rate and/or the solvent temperature to optimize the acid gas removal process. In particular, in some embodiments, the controller **224** may adjust the overall solvent flow/circulation rate for the gas processing system **200** by, for example, adjusting the operating parameters of the variable speed drive corresponding to the pump **216** and/or a flow control valve (not shown) located downstream of the pump **216**. In other embodiments, the controller **224** may adjust the solvent flow rate for each co-current contacting system **202A-C** separately by adjusting the operating parameters of the variable speed drive corresponding to pumps (not shown) and/or flow control valves (not shown) located upstream of each co-current contacting system **202A-C**. In addition, the controller **224** may adjust the solvent temperature by, for example, directing the temperature controller of the heat exchanger **218** to increase or decrease the operating temperature. However, one of skill in the art will appreciate that there are additional or alternative means of adjusting the solvent flow rate and/or the solvent temperature, depending on the details of the specific implementation.

[0087] Furthermore, the solvent flow rate and/or the solvent temperature may be adjusted to optimize the acid gas removal process in various ways. For example, such adjustments may be used to, for example, increase the H₂S selectivity of the process. Specifically, according to embodiments described herein, measuring the outlet temperature of each stage allows the CO₂ pickup of each stage to be estimated. This information can then be used to adjust the operating parameters for each stage such that the H₂S pickup is maximized, while the CO₂ pickup is minimized. As an example, this may be accomplished by increasing the solvent flow rate for the first stage, while reducing the solvent flow rate for the second and third stages. As another example, this may be accomplished by increasing the solvent flow rate for the first and second stages, while turning off the third stage completely. Similarly, this may be accomplished by reducing the solvent temperature to allow for enhanced H₂S removal.

[0088] In some embodiments, the acid gas loading conditions relating to the gas processing system **200** can be used as a feedforward control for one or more downstream processes. For example, if the acid gas loading conditions indicate that the amount of CO₂ pickup is increasing

relative to the amount of H₂S pickup, the operator, via the computing system, may direct the process control scheme of a downstream acid gas enrichment process to adjust the operating conditions (e.g., the circulation rate) in anticipation of the new flow rate, thus allowing for more stable operation. Depending on the sulfur recovery process, this may improve the ability to remain within regulatory requirements for emissions.

[0089] In addition, for embodiments with high acid gas removal levels, the total acid gas loading can be continuously (or periodically) monitored to determine whether the acid gas loading conditions exceed a predetermined acid gas loading limit. If the acid gas loading limit is exceeded, the controller 224 may respond by increasing the overall solvent flow/circulation rate (or individual solvent flow rates) to avoid operating at conditions that are favorable for corrosion.

[0090] Furthermore, in some embodiments, the measured acid gas loading conditions are used to determine suitable changes to the configuration of the gas processing system 200. For example, in such embodiments, one or more additional co-current contacting systems may be added to the gas processing system 200 to accommodate a desired level of acid gas removal.

[0091] The process flow diagram of FIG. 2 is not intended to indicate that the gas processing system 200 is to include all of the components shown in FIG. 2. Moreover, it will be appreciated by one of skill in the art that the gas processing system 200 will include a number of additional components not shown in the simplified process flow diagram of FIG. 2. For example, any number of additional co-current contacting systems may be included within the gas processing system 200. Furthermore, details relating to examples of additional components that may be included within the gas processing system 200 are described with respect to the exemplary embodiment shown in FIG. 3.

[0092] While the gas processing system 200 is depicted in FIG. 2 with the co-current contacting systems 202A-C arranged in series, in other embodiments, the co-current contacting systems 202A-C are arranged in parallel. In such embodiments, the lean solvent stream 214 may be split between the co-current contacting systems 202A-C. Therefore, the solvent flow rate may differ for each co-current contacting system 202A-C (and, notably, may not be equal to the overall solvent circulation rate). Accordingly, in such embodiments, the gas processing system 200 may include flow meters located upstream of each co-current contacting system 202A-C, rather than the single flow meter 222B for measuring the solvent flow/circulation rate as shown in FIG. 2.

Such flow meters may be configured to measure the solvent flow rate for each co-current contacting system **202A-C** separately, and send the resulting measurements to the controller **224**, as described herein.

[0093] Additionally or alternatively, for some embodiments in which the co-current contacting systems **202A-C** are arranged in parallel, the sour feed gas stream **204** may be split between the co-current contacting systems **202A-C**. Therefore, the gas flow rate may differ for each co-current contacting system **202A-C**. Accordingly, in such embodiments, the gas processing system **200** may include flow meters located upstream of each co-current contacting system **202A-C**, rather than the single flow meter **222A** for measuring the gas flow rate as shown in **FIG. 2**. Such flow meters may be configured to measure the gas flow rate for each co-current contacting system **202A-C** separately, and send the resulting measurements to the controller **224**, as described herein.

[0094] **FIG. 3** is a more detailed process flow diagram of another exemplary gas processing system **300** for which the acid gas loading control techniques described herein may be implemented. The gas processing system **300** is used for the removal of acid gas components (i.e., H_2S and CO_2) from a sour feed gas stream **302**, as described with respect to **FIG. 2**. The gas processing system **300** employs a number of co-current contacting systems **304A-F**. Each co-current contacting system **304A-F** may include a co-current contactor and a separator, as described further with respect to **FIG. 4**.

[0095] The sour feed gas stream **302** may be, for example, a natural gas stream from a hydrocarbon production operation, a flue gas stream from a power plant, or a synthesis gas (syn-gas) stream. If the sour feed gas stream **302** is a syn-gas stream, the sour feed gas stream **302** may be cooled and filtered before being introduced into the gas processing system **300**. The sour feed gas stream **302** may also be a flash gas stream taken from a flash drum in a gas processing facility itself. In addition, the sour feed gas stream **302** may be a tail gas stream from a Claus sulfur recovery process or an impurities stream from a solvent regenerator. Furthermore, the sour feed gas stream **302** may be an exhaust emission from a cement plant or other industrial plant. In this instance, CO_2 may be absorbed from excess air or from a nitrogen-containing flue gas.

[0096] The sour feed gas stream **302** includes a non-absorbing gas, such as methane, and one or more impurities, such as CO_2 and H_2S . In some embodiments, the sour feed gas stream **302** includes a large amount of H_2S , such as, for example, on the order of 1,000 ppm H_2S . According

to embodiments described herein, the gas processing system **300** converts the sour feed gas stream **302** into a sweetened gas stream **306** by removing the CO₂ and H₂S. In various embodiments, the sweetened gas stream **306** contains concentrations of less than 4 ppm H₂S and less than 2-3 vol. % CO₂.

5 **[0097]** In operation, the sour feed gas stream **302** is flowed into a first co-current contacting system **304A**, where it is mixed with a solvent stream **308**. In various embodiments, the solvent stream **308** includes any suitable type of solvent solution, such as monoethanolamine (MEA), 2(2-aminoethoxy) ethanol [Diglycolamine® (DGA)], diethanolamine (DEA), diisopropanolamine (DIPA), methyldiethanolamine (MDEA), triethyleneamine, FLEXSORB® SE, 2-amino-2-methyl-1-propanol (AMP), and/or formulated amines such as FLEXSORB® SE PLUS, the
10 UCARSOL™ family of products, or formulated MDEA solutions. Moreover, the solvent stream **308** entering the first co-current contacting system **304A** is a lean (or semi-lean) solvent stream that has undergone a desorption process for the removal of acid gas impurities. More specifically, in the embodiment shown in **FIG. 3**, the solvent stream **308** is a semi-lean solvent that is taken
15 from a central portion of a regenerator **310**. In addition, a lean solvent stream **312** taken from the regenerator **310** is also directed into the fifth and final co-current contacting systems **304E** and **304F**.

[0098] In various embodiments, the gas processing system **300** employs a series of co-current contacting systems **304A-F**. Each co-current contacting system **304A-F** removes a portion of the
20 acid gas content from the sour feed gas stream **302**, thereby releasing a progressively sweetened gas stream in a downstream direction. The final co-current contacting system **304F** provides the final sweetened gas stream **306**.

[0099] Before entering the first co-current contacting system **304A**, the sour feed gas stream **302** passes through an inlet separator **314**. The inlet separator **314** cleans the sour feed gas stream
25 **302** by filtering out impurities, such as brine and drilling fluids. Some particle filtration may also take place. Such cleaning of the sour feed gas stream **302** helps to prevent the solvent from foaming during the acid gas removal process.

[0100] In some embodiments, the sour feed gas stream **302** is also pretreated upstream of the inlet separator **314** or the first co-current contacting system **304A**. For example, the sour feed gas
30 stream **302** may undergo a water wash to remove glycol or other chemical additives. This may be

accomplished via a separate processing loop (not shown) wherein water is introduced to the gas, such as via an additional co-current contacting system. Water has an affinity for glycol and will pull the glycol out of the sour feed gas stream **302**. This, in turn, will help control foaming within the co-current contacting systems **304A-F**. In the case of flue gas applications, corrosion inhibitors
5 may be added to the solvent to retard the reaction of O₂ with the steel in the processes.

[0101] As shown in **FIG. 3**, the solvent stream **308** is flowed into the first co-current contacting system **304A**. Movement of the solvent stream **308** into the first co-current contacting system **304A** is aided by a heat exchanger (i.e., a cooler) **316** and several pumps **318A** and **318B**. The heat exchanger **316** cools the solvent stream **308** such that it flows into the first co-current
10 contacting system **304A** at a suitable temperature, while the pumps **318A** and **318B** increase the pressure of the solvent stream **308** such that it flows into the first co-current contacting system **304A** at a suitable pressure of, for example, about 15 psia to about 1,500 psig.

[0102] Once inside the first co-current contacting system **304A**, the sour feed gas stream **302** and the solvent stream **308** move along the longitudinal axis of the first co-current contacting system **304A**. As they travel, the liquid amine (or other solvent solution) interacts with the H₂S and CO₂ in the sour feed gas stream **302**, causing the H₂S and CO₂ to chemically attach to or be absorbed by the amine molecules. A first partially-loaded, or “rich,” solvent stream **320A** is then
15 flowed out of a bottom portion of the first co-current contacting system **304A**. In addition, a first partially-sweetened gas stream **322A** is flowed out of a top portion of the first co-current contacting system **304A** and into a second co-current contacting system **304B**.

[0103] According to the embodiment shown in **FIG. 3**, a third co-current contacting system **304C** is provided after the second co-current contacting system **304B**, and a fourth co-current contacting system **304D** is provided after the third co-current contacting system **304C**. In addition, a fifth co-current contacting system **304E** is provided after the fourth co-current contacting system
25 **304D**, and a final co-current contacting system **304F** is provided after the fifth co-current contacting system **304E**. Each of the second, third, fourth, and fifth co-current contacting systems **304B**, **304C**, **304D**, and **304E** generates a respective partially-sweetened gas stream **322B**, **322C**, **322D**, and **322E**. In addition, each of the second, third, fourth, fifth, and final co-current contacting systems **304B**, **304C**, **304D**, **304E**, and **304F** generates a respective partially-loaded solvent stream
30 **320B**, **320C**, **320D**, **320E**, and **320F**. If an amine is used as the solvent stream **308**, the partially-

loaded solvent streams **320A-F** includes rich amine solutions. In the gas processing system **300** of **FIG. 3**, the second partially-loaded solvent stream **320B** merges with the first partially-loaded solvent stream **320A** and goes through a regeneration process in the regenerator **310**.

[0104] As the progressively-sweetened gas streams **322A-E** are generated, the gas pressure in the gas processing system **300** progressively decreases. As this occurs, the liquid pressure of the progressively-richer solvent streams **320A-F** are correspondingly increased. In various embodiments, this is accomplished by placing one or more booster pumps (not shown) between each co-current contacting system **304A-F** to boost liquid pressure in the gas processing system **300**.

[0105] In the gas processing system **300**, solvent streams are regenerated by flowing the partially-loaded solvent streams **320A** and **320B** through a flash drum **324**. Absorbed natural gas **326** is flashed from the partially-loaded solvent streams **320A** and **320B** within the flash drum **324** and is then flowed out of the flash drum **324** via an overhead line **328**.

[0106] The resulting rich solvent stream **330** is flowed from the flash drum **324** to the regenerator **310**. The rich solvent stream **330** is introduced into the regenerator **310** for desorption. In various embodiments, the regenerator **310** includes a stripper portion **332** including trays or other internals (not shown). The stripper portion **332** is located directly above a reboiler portion **334**. A heat source **336** is provided with the reboiler portion **334** to generate heat. The regenerator **310** produces the regenerated, lean solvent stream **312** that is recycled for re-use in the fifth and final co-current contacting systems **304E** and **304F**. Stripped overhead gas from the regenerator **310**, which may include concentrated H_2S and CO_2 , is flowed out of the regenerator **310** as an overhead impurities stream **338**.

[0107] The overhead impurities stream **338** is flowed into a condenser **340**, which cools the overhead impurities stream **338**. The resulting cooled impurities stream **342** is then flowed through a reflux accumulator **344**. The reflux accumulator **344** separates any remaining liquid, such as condensed water, from the impurities stream **342**. This results in the generation of a substantially pure acid gas stream **346**, which is flowed out of the reflux accumulator **344** via an overhead line **348**.

[0108] In some embodiments, the H_2S in the acid gas stream **346** is then converted into elemental sulfur using a sulfur recovery unit (not shown). The sulfur recovery unit may be a so-

called Claus unit. Those of ordinary skill in the art will understand that a “Claus process” is a process that is sometimes used by the natural gas and refinery industries to recover elemental sulfur from H₂S-containing gas streams.

[0109] In practice, the “tail gas” from the Claus process, which may include H₂S, SO₂, CO₂, N₂, and water vapor, can be reacted to convert the SO₂ to H₂S via hydrogenation. The hydrogenated tail gas stream has a high partial pressure, a large amount of CO₂, e.g., more than 50%, and a small amount of H₂S, e.g., a few percent or less. This type of gas stream, which is typically near atmospheric pressure, is amenable to selective H₂S removal. The recovered H₂S may be recycled to the front of the Claus unit, or may be sequestered downstream. Alternatively, a direct oxidation of the H₂S to elemental sulfur may be performed using various processes known in the field of gas separation.

[0110] Because the H₂S reaction is instantaneous relative to the CO₂ reactions, as described with respect to Equations (1) and (2), lowering the residence time, i.e., the contact time between the vapor and liquid phases, will result in less CO₂ being absorbed into the solvent. Therefore, the design of the co-current contacting systems **304A-F** enhances selective H₂S removal due to the short contact time inherent in the equipment design.

[0111] As shown in **FIG. 3**, a residual liquid stream **350** is flowed out of the bottom of the reflux accumulator **344**. The residual liquid stream **350** is then flowed through a reflux pump **352**, which boosts the pressure of the residual liquid stream **350** and pumps the residual liquid stream **350** into the regenerator **310**. The residual liquid stream **350** is flowed out of the regenerator **310**, for example, from the bottom of the reboiler portion **334** as part of the lean solvent stream **312**. Some water may be added to the lean solvent stream **312** to balance the loss of water vapor to the sweetened gas stream **306** and the acid gas stream **346**. This water may be added at an intake or suction of the reflux pump **352**.

[0112] In various embodiments, the lean solvent stream **312** is at a low pressure. Accordingly, the lean solvent stream **312** is passed through a pressure boosting pump **354**. From the pressure boosting pump **354**, the lean solvent stream **312** is flowed through a heat exchanger (i.e., a cooler) **356**. The heat exchanger **356** cools the lean solvent stream **312** back to near ambient temperatures after it has been heated by the regenerator **310**.

[0113] In some embodiments, the lean solvent stream **312** is then flowed into a solvent tank **358**. In other embodiments, the solvent tank **358** is off-line and provides a reservoir for the lean solvent stream **312**. In addition, in some embodiments, movement of the lean solvent stream **312** towards the fifth and final co-current contacting systems **304E** and **304F** is aided by a pump **360**.

5 The pump **360** causes the lean solvent stream **312** to flow at a suitable pressure, for example, of about 15 psia to about 1,100 psig.

[0114] In various embodiments, a first portion **362** of the lean solvent stream **312** is joined with the partially-loaded solvent stream **320F** and flowed into the fifth co-current contacting system **304E**. A second portion **364** of the lean solvent stream **312** is flowed into a solvent treater **366**, which is configured to treat the lean solvent stream **312** to produce an enhanced solvent stream **368**. According to embodiments described herein, the enhanced solvent stream **368** is a treated solvent stream that is capable of absorbing a higher concentration of acid gas than the lean solvent stream **312**. The enhanced solvent stream **368** may be a highly H₂S-selective solvent stream that is capable of selectively absorbing a higher concentration of H₂S as opposed to CO₂. In various
15 embodiments, an H₂S concentration of less than 4 ppm within the final sweetened gas stream **306** is achieved using the enhanced solvent stream **368**.

[0115] In various embodiments, the solvent treater **366** is a chiller that is configured to produce the enhanced solvent stream **368** by cooling the lean solvent stream **312** to at least about ambient, such as about 20 °C to 25 °C, or to at least about 5 °C below ambient, or to at least about 10 °C
20 below ambient, or to at least about 20 °C below ambient, or to a temperature that is the same as, or slightly lower than, that of the partially-sweetened gas stream **322E** entering the final co-current contacting system **304F**. For example, the solvent treater **366** may be an ammonia chiller, a cold water flow from a cooling water tower, or any other suitable type of chiller.

[0116] Furthermore, in various embodiments, the gas processing system **300** includes a
25 controller (not shown) that is configured to control the operation of the solvent treater **366**, pumps **318A**, **318B**, **354**, **360**, heat exchangers **316** and **356**, regenerator **310**, and other equipment within the gas processing system **300**. In operation, the controller performs this function by communicating (e.g., via wired and wireless means) with a computing system that is controlled by the operator of the gas processing system **300**.

[0117] According to embodiments described herein, the gas processing system **300** includes a number of temperature sensors **370A-M** that are configured to separately measure the inlet temperatures of the gas streams **302**, **322A**, **322B**, **322C**, **322D**, and **322E** and the solvent streams **308**, **320C**, **320D**, **320E**, **320F**, and **368** entering the respective co-current contacting systems **304A-F**, as well as the outlet temperatures of the gas streams **322A**, **322B**, **322C**, **322D**, **322E**, and **306** exiting the respective co-current contacting systems **304A-F**. In addition, the gas processing system includes flow meters **372A**, **372B**, **372C**, and **372D** that are configured to measure the flow rates of the sour feed gas stream **302** and the solvent streams **308**, **362**, and **368**, respectively, flowing into the co-current contacting systems **304A**, **304E**, and **304F**. Moreover, as described in more detail with respect to **FIG. 2**, the temperature and flow rate measurements received from the temperature sensors **370A-M** and flow meters **370A-D**, respectively, are then used by the computing system, in conjunction with the controller, to control the acid gas loading conditions within the gas processing system **300** according to the techniques described herein. Specifically, the computing system uses the recorded flow rates and inlet/outlet temperatures received from the controller to calculate the total acid gas pickup corresponding to each stage of the acid gas removal process (i.e., corresponding to each co-current contacting system **304A-F**) using the heat balance for the mixed system, as described with respect to Equations (3)-(7). In various embodiments, this allows for the determination of the total amount of H_2S and CO_2 that was absorbed by the solvent at each stage of the process. Moreover, for embodiments in which it is desirable to separately determine the amount of H_2S and the amount of CO_2 that was absorbed by the solvent at each stage of the process, H_2S analyzers (not shown) may optionally be provided upstream and downstream of each co-current contacting system **304A-F**. It is then trivial to subtract the amount of absorbed H_2S , as determined by the H_2S analyzers, from the total acid gas loading to derive the amount of CO_2 absorbed at each stage of the process.

[0118] As described with respect to **FIG. 2**, the computing system, in conjunction with the controller, utilizes the calculated acid gas loading conditions to determine appropriate operating parameter adjustments that will optimize the acid gas removal process. In particular, the computing system may direct the controller to adjust the operation of the solvent treater **366**, pumps **318A**, **318B**, **354**, **360**, heat exchangers **316** and **356**, regenerator **310**, and/or other

equipment within the gas processing system **300**. Such adjustments may be used to, for example, increase the H₂S selectivity of the acid gas removal process.

[0119] The process flow diagram of **FIG. 3** is not intended to indicate that the gas processing system **300** is to include all of the components shown in **FIG. 3**. Further, any number of additional components may be included within the gas processing system **300**, depending on the details of the specific implementation. For example, the gas processing system **300** may include any suitable types of heaters, chillers, condensers, liquid pumps, gas compressors, blowers, bypass lines, other types of separation and/or fractionation equipment, valves, switches, controllers, and pressure-measuring devices, temperature-measuring devices, level-measuring devices, or flow-measuring devices, among others. Moreover, the gas processing system **300** may include any number of additional co-current contacting systems not shown in **FIG. 3**, or it may include fewer co-current contacting systems than shown in **FIG. 3**. Furthermore, one of skill in the art will appreciate that any number of alternative configurations can be envisioned for the gas processing system **300**, depending on the details of the specific implementation. Indeed, the gas processing system **300** of **FIG. 3** is only meant to serve as an illustrative example of one type of gas processing system for which the acid gas loading control techniques described herein may be implemented.

[0120] While the gas processing system **300** is depicted in **FIG. 3** with the co-current contacting systems **304A-F** arranged in series, in other embodiments, the co-current contacting systems **304A-F** may be arranged in parallel. In such embodiments, additional flow meters may be positioned in suitable locations within the gas processing system **300** to measure the solvent flow rate and/or the gas flow rate for each co-current contacting system separately, as described with respect to **FIG. 2**.

[0121] **FIG. 4** is a schematic view of an exemplary co-current contacting system **400** that can be used to provide a gas processing system with a co-current flow scheme according to embodiments described herein. The co-current contacting system **400** provides for the separation of components within a gas stream. In addition, the co-current contacting system **400** aids in the implementation of various gas processing systems, such as the gas processing systems **200** and **300** of **FIGS. 2** and **3**, respectively, where the rapid separation of components is desired. In some embodiments, the co-current contacting system **400** is one of the co-current contacting systems **202A-C** and **304A-F** described with respect to **FIGS. 2** and **3**.

[0122] The co-current contacting system 400 includes a co-current contactor 402 that is positioned in-line within a pipe 404. The co-current contactor 402 includes a number of components that provide for the efficient contacting of a liquid solvent stream with a flowing gas stream 406. The liquid solvent stream can be used for the separation of acid gases (e.g., H₂S and CO₂) from the gas stream 406.

[0123] In various embodiments, the co-current contactor 402 includes a mixer 408 and a mass transfer section 410. As shown in FIG. 4, the gas stream 406 is flowed through the pipe 404 and into the mixer 408. A liquid solvent stream 412 is also flowed into the mixer 408, for example, through a hollow space 414 coupled to flow channels 416 in the mixer 408.

[0124] From the flow channels 416, the liquid solvent stream 412 is released into the gas stream 406 as fine droplets through injection orifices 418 and is then flowed into the mass transfer section 410. This results in the generation of a treated gas stream 420 within the mass transfer section 410. The treated gas stream 420 includes small liquid droplets dispersed in a gas phase. The liquid droplets include acid gases from the gas stream 406 that were absorbed or dissolved into the liquid solvent stream 412.

[0125] The treated gas stream 420 is then flowed from the mass transfer section 410 to a separator 422, such as a cyclonic separator, a mesh screen, or a settling vessel. The separator 422 removes the liquid droplets from the gas phase. The liquid droplets include the original liquid solvent stream with the absorbed acid gases 424, and the gas phase includes a sweetened gas stream 426 that has been purified via the removal of H₂S and CO₂.

[0126] The schematic view of FIG. 4 is not intended to indicate that the co-current contacting system 400 is to include all of the components shown in FIG. 4. Moreover, any number of additional components may be included within the co-current contacting system 400, depending on the details of the specific implementation. Furthermore, while embodiments described herein are specifically adapted to gas processing systems including a co-current flow scheme, it will be appreciated by one of skill in the art that any number of alternative configurations for the gas processing system and the corresponding co-current contacting systems can be envisioned without negatively impacting the overall technical effect of the techniques described herein.

[0127] Improved Method for Controlling Acid Gas Loading within Gas Processing System

[0128] FIG. 5 is a process flow diagram of a method 500 for controlling acid gas loading within a gas processing system. The method 500 begins at block 502, at which a sour feed gas stream including acid gases, e.g., H₂S and CO₂, is contacted with a solvent stream within co-current contacting systems of a gas processing system to generate a sweetened gas stream and a rich solvent stream including absorbed acid gases. At block 504, the absorbed acid gases are removed from the rich solvent stream within a regenerator of the gas processing system to regenerate the solvent stream.

[0129] At block 506, the gas flow rate for the sour feed gas stream and the solvent flow rate for the solvent stream are measured via corresponding flow meters within the gas processing system. For example, for embodiments in which the co-current contacting systems are configured in series, such flow meters may be configured to measure the inlet flow rates (or circulate rates) of the gas and solvent streams as they begin flowing through the co-current contacting systems. As another example, for embodiments in which the co-current contacting systems are configured in parallel such that the solvent stream is split between the co-current contacting systems, one flow meter may be configured to measure the inlet flow rate of the gas stream as it begins flowing through the co-current contacting systems, while additional flow meters may be configured to separately measure the inlet flow rates of the solvent streams entering each co-current contacting system. As yet another example, for embodiments in which the co-current contacting systems are configured in parallel such that the gas stream is split between the co-current contacting systems, one flow meter may be configured to measure the inlet flow rate of the solvent stream as it begins flowing through the co-current contacting systems, while additional flow meters may be configured to separately measure the inlet flow rates of the gas streams entering each co-current contacting system. However, as will be appreciated by one of skill in the art, there are various means of measuring such flow rates, and the specific details for the configuration of the flow meters and the type(s) of flow meter used may be adapted to each specific implementation.

[0130] At block 508, the liquid inlet temperature and/or the gas inlet temperature for each co-current contacting system is measured via a corresponding temperature sensor positioned upstream of each co-current contacting system. In some embodiments, this includes measuring both the liquid inlet temperature and the gas inlet temperature upstream of each co-current contacting system.

[0131] At block 510, the liquid outlet temperature and/or the gas outlet temperature for each co-current contacting system is measured via a corresponding temperature sensor positioned downstream of each co-current contacting system. In some embodiments, this includes measuring the gas outlet temperature downstream of each co-current contacting system, while assuming that the liquid outlet temperature for each co-current contacting system is approximately the same as the corresponding gas outlet temperature.

[0132] At block 512, the amount of acid gases absorbed by the solvent stream within each co-current contacting system is determined based on the gas flow rate, the solvent flow rate, the liquid and/or gas inlet temperatures, and the liquid and/or gas outlet temperatures, in combination with the heat of reaction between the acid gases and the solvent stream. According to embodiments described herein, this is accomplished using the heat balance for the mixed system, as described with respect to Equations (3)-(7).

[0133] At block 514, any number of operating parameters corresponding to the gas processing system are adjusted based on the determined amount of acid gases absorbed by the solvent stream within each co-current contacting system. In some embodiments, this includes dynamically adjusting the reboiler duty of the regenerator based on fluctuations in the amount of acid gases absorbed by the solvent stream within each co-current contacting system. Additionally or alternatively, in some embodiments, this includes dynamically adjusting the solvent flow rate and/or the solvent temperature based on fluctuations in the amount of acid gases absorbed by the solvent stream within each co-current contacting system. This may be used to, for example, provide for enhanced H₂S removal from the sour feed gas stream. Moreover, in such embodiments, this may include adjusting the overall solvent flow/circulation rate (i.e., for the counter-current configuration in which the co-current contacting systems are connected in series), or this may include adjusting the solvent flow rate to each co-current contacting system (i.e., for the configuration in which the co-current contacting systems are connected in parallel). Additionally or alternatively, in some embodiments, this includes monitoring the amount of acid gases absorbed by the solvent stream within each co-current contacting system to determine whether a total amount of absorbed acid gases exceeds a predetermined acid gas loading limit and, if the total amount of absorbed acid gases exceeds the predetermined acid gas loading limit, increasing the solvent flow rate to avoid operating at conditions that are favorable for corrosion.

[0134] The process flow diagram of **FIG. 5** is not intended to indicate that the steps of the method **500** are to be executed in any particular order, or that all of the steps of the method **500** are to be included in every case. Moreover, any number of additional steps not shown in **FIG. 5** may be included within the method **500**, depending on the details of the specific implementation.

5 For example, in some embodiments, the method **500** also includes measuring the amount of H₂S absorbed by the solvent stream within each co-current contacting system via an H₂S analyzer positioned downstream of each co-current contacting system, as well as determining the amount of CO₂ absorbed by the solvent stream within each co-current contacting system by subtracting the amount of H₂S absorbed by the solvent stream from the total amount of acid gases absorbed
10 by the solvent stream for each co-current contacting system.

[0135] In some embodiments, the method **500** also includes adjusting operating parameters corresponding a downstream process based on the determined amount of acid gases absorbed by the solvent stream within each co-current contacting system of the gas processing system. For example, if the downstream process is a downstream acid gas enrichment process, the solvent
15 circulation rate corresponding to the downstream acid gas enrichment process may be increased in response to fluctuations in the amount of acid gases absorbed by the solvent stream within each co-current contacting system of the gas processing system. Furthermore, in some embodiments, the method **500** includes adjusting the configuration of the gas processing system based on the amount of acid gases absorbed by the solvent stream within each co-current contacting system.

20 For example, in such embodiments, at least one additional co-current contacting system may be added to the gas processing system to optimize the acid gas removal process.

[0136] Exemplary Computing System for Implementing Acid Gas Loading Control Techniques Described Herein

[0137] **FIG. 6** is a block diagram of an exemplary cluster computing system **600** that may be
25 utilized to implement the acid gas loading control techniques described herein. Specifically, the cluster computing system **600**, or some variation thereof, may receive input from, and provide feedback to, the controller of the gas processing system that is being used to implement the techniques described herein.

[0138] The exemplary cluster computing system **600** shown in **FIG. 6** has four computing
30 units **602A**, **602B**, **602C**, and **602D**, each of which may perform calculations for a portion of the

acid gas loading control techniques described herein. However, one of ordinary skill in the art will recognize that the cluster computing system **600** is not limited to this configuration, as any number of computing configurations may be selected. For example, a smaller analysis may be run on a single computing unit, such as a workstation, while a large calculation may be run on a cluster computing system **600** having tens, hundreds, thousands, or even more computing units.

[0139] The cluster computing system **600** may be accessed from any number of client systems **604A** and **604B** over a network **606**, for example, through a high-speed network interface **608**. The computing units **602A** to **602D** may also function as client systems, providing both local computing support and access to the wider cluster computing system **600**.

[0140] The network **606** may include a local area network (LAN), a wide area network (WAN), the Internet, or any combinations thereof. Each client system **604A** and **604B** may include one or more non-transitory, computer-readable storage media for storing the operating code and program instructions that are used to implement the acid gas loading control techniques described herein. For example, each client system **604A** and **604B** may include a memory device **610A** and **610B**, which may include random access memory (RAM), read only memory (ROM), and the like. Each client system **604A** and **604B** may also include a storage device **612A** and **612B**, which may include any number of hard drives, optical drives, flash drives, or the like.

[0141] The high-speed network interface **608** may be coupled to one or more buses in the cluster computing system **600**, such as a communications bus **614**. The communication bus **614** may be used to communicate instructions and data from the high-speed network interface **608** to a cluster storage system **616** and to each of the computing units **602A** to **602D** in the cluster computing system **600**. The communications bus **614** may also be used for communications among the computing units **602A** to **602D** and the cluster storage system **616**. In addition to the communications bus **614**, a high-speed bus **618** can be present to increase the communications rate between the computing units **602A** to **602D** and/or the cluster storage system **616**.

[0142] The cluster storage system **616** can have one or more non-transitory, computer-readable storage media, such as storage arrays **620A**, **620B**, **620C** and **620D** for the storage of models, data, visual representations, results, code, and other information concerning the implementation of the acid gas loading control techniques described herein. The storage arrays **620A** to **620D** may include any combinations of hard drives, optical drives, flash drives, or the like.

[0143] Each computing unit **602A** to **602D** can have a processor **622A**, **622B**, **622C** and **622D** and associated local non-transitory, computer-readable storage media, such as a memory device **624A**, **624B**, **624C** and **624D** and a storage device **626A**, **626B**, **626C** and **626D**. Each processor **622A** to **622D** may be a multiple core unit, such as a multiple core central processing unit (CPU) or a graphics processing unit (GPU). Each memory device **624A** to **624D** may include ROM and/or RAM used to store program instructions for directing the corresponding processor **622A** to **622D** to implement the acid gas loading control techniques described herein. Each storage device **626A** to **626D** may include one or more hard drives, optical drives, flash drives, or the like. In addition, each storage device **626A** to **626D** may be used to provide storage for models, intermediate results, data, images, or code associated with operations, including code used to implement the acid gas loading control techniques described herein.

[0144] The present techniques are not limited to the architecture or unit configuration illustrated in **FIG. 6**. For example, any suitable processor-based device may be utilized for implementing all or a portion of embodiments of the acid gas loading control techniques described herein, including without limitation personal computers, laptop computers, computer workstations, mobile devices, and multi-processor servers or workstations with (or without) shared memory. Moreover, embodiments may be implemented on application specific integrated circuits (ASICs) or very-large-scale integrated (VLSI) circuits. In fact, persons of ordinary skill in the art may utilize any number of suitable structures capable of executing logical operations according to embodiments described herein.

[0145] **FIG. 7** is a block diagram of an exemplary non-transitory, computer-readable storage medium **700** that may be used for the storage of data and modules of program instructions for implementing the acid gas loading control techniques described herein. The non-transitory, computer-readable storage medium **700** may include a memory device, a hard disk, and/or any number of other devices, as described with respect to **FIG. 6**. A processor **702** may access the non-transitory, computer-readable storage medium **700** over a bus or network **704**. While the non-transitory, computer-readable storage medium **700** may include any number of modules (and sub-modules) for implementing the techniques described herein, in some embodiments, the non-transitory, computer-readable storage medium **700** includes an acid gas loading determination module **706** for estimating the acid gas loading conditions within a gas processing system that is

performing an acid gas removal process and a process optimization module **708** for adjusting various parameters within the gas processing system to optimize the acid gas removal process.

[0146] Moreover, while the embodiments described herein are well-calculated to achieve the advantages set forth, it will be appreciated that such embodiments are susceptible to modification, variation, and change without departing from the spirit thereof. Indeed, the present techniques
5 include all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

CLAIMS

What is claimed is:

1. A method for controlling acid gas loading within a gas processing system,
5 comprising:

contacting a sour feed gas stream comprising acid gases with a solvent stream within co-current contacting systems of a gas processing system to generate a sweetened gas stream and a rich solvent stream comprising absorbed acid gases;

removing the absorbed acid gases from the rich solvent stream within a regenerator of the
10 gas processing system to regenerate the solvent stream;

measuring a gas flow rate for the sour feed gas stream and a solvent flow rate for the solvent stream via corresponding flow meters within the gas processing system;

measuring at least one of a liquid inlet temperature or a gas inlet temperature for each co-current contacting system via a corresponding temperature sensor positioned
15 upstream of each co-current contacting system;

measuring at least one of a liquid outlet temperature or a gas outlet temperature for each co-current contacting system via a corresponding temperature sensor positioned downstream of each co-current contacting system;

determining an amount of acid gases absorbed by the solvent stream within each co-current
20 contacting system based on the gas flow rate, the solvent flow rate, the at least one of the liquid inlet temperature or the gas inlet temperature, and the at least one of the liquid outlet temperature or the gas outlet temperature, in combination with a heat of reaction between the acid gases and the solvent stream; and

adjusting operating parameters corresponding to the gas processing system based on the
25 determined amount of acid gases absorbed by the solvent stream within each co-current contacting system.

2. The method of claim 1, wherein the acid gases comprise H₂S and CO₂, and wherein the method further comprises:

measuring an amount of H₂S absorbed by the solvent stream within each co-current contacting system via an H₂S analyzer positioned downstream of each co-current contacting system; and

determining an amount of CO₂ absorbed by the solvent stream within each co-current contacting system by subtracting the amount of H₂S absorbed by the solvent stream from the amount of acid gases absorbed by the solvent stream for each co-current contacting system.

3. The method of claim 1 or 2, comprising:

measuring both the liquid inlet temperature and the gas inlet temperature upstream of each co-current contacting system; and

measuring the gas outlet temperature downstream of each co-current contacting system, while assuming that the liquid outlet temperature for each co-current contacting system is approximately the same as the corresponding gas outlet temperature.

4. The method of any of claims 1 to 3, wherein adjusting the operating parameters corresponding to the gas processing system comprises dynamically adjusting a reboiler duty of the regenerator based on fluctuations in the amount of acid gases absorbed by the solvent stream within each co-current contacting system.

5. The method of any of claims 1 to 4, wherein adjusting the operating parameters corresponding to the gas processing system comprises dynamically adjusting at least one of the solvent flow rate or a solvent temperature based on fluctuations in the amount of acid gases absorbed by the solvent stream within each co-current contacting system.

6. The method of claim 5, comprising dynamically adjusting the at least one of the solvent flow rate or the solvent temperature to provide for enhanced H₂S removal from the sour feed gas stream.

7. The method of any of claims 1 to 6, comprising adjusting operating parameters corresponding a downstream process based on the determined amount of acid gases absorbed by the solvent stream within each co-current contacting system of the gas processing system.

5 8. The method of claim 7, wherein the downstream process comprises a downstream acid gas enrichment process, and wherein adjusting the operating parameters comprises increasing a solvent flow rate corresponding to the downstream acid gas enrichment process in response to fluctuations in the amount of acid gases absorbed by the solvent stream within each co-current contacting system of the gas processing system.

10 9. The method of any of claims 1 to 8, wherein adjusting the operating parameters corresponding to the gas processing system comprises:

monitoring the amount of acid gases absorbed by the solvent stream within each co-current contacting system to determine whether a total amount of absorbed acid gases
15 exceeds a predetermined acid gas loading limit; and

if the total amount of absorbed acid gases exceeds the predetermined acid gas loading limit, increasing the solvent flow rate to avoid operating at conditions that are favorable for corrosion.

20 10. The method of any of claims 1 to 9, comprising adjusting a configuration of the gas processing system based on the amount of acid gases absorbed by the solvent stream within each co-current contacting system.

25 11. The method of claim 10, wherein adjusting the configuration of the gas processing system comprises adding at least one additional co-current contacting system to optimize an operation of the gas processing system.

12. A computing system, comprising:
a processor; and

a non-transitory, computer-readable storage medium, comprising code configured to direct the processor to:

instruct a controller of a gas processing system to:

contact a sour feed gas stream comprising acid gases with a solvent stream within co-current contacting systems of the gas processing system to generate a sweetened gas stream and a rich solvent stream comprising absorbed acid gases;

remove the absorbed acid gases from the rich solvent stream within a regenerator of the gas processing system to regenerate the solvent stream;

measure a gas flow rate for the sour feed gas stream and a solvent flow rate for the solvent stream via corresponding flow meters within the gas processing system;

measure at least one of a liquid inlet temperature or a gas inlet temperature for each co-current contacting system via a corresponding temperature sensor positioned upstream of each co-current contacting system; and

measure at least one of a liquid outlet temperature or a gas outlet temperature for each co-current contacting system via a corresponding temperature sensor positioned downstream of each co-current contacting system;

determine an amount of acid gases absorbed by the solvent stream within each co-current contacting system based on the gas flow rate, the solvent flow rate, the at least one of the liquid inlet temperature or the gas inlet temperature, and the at least one of the liquid outlet temperature or the gas outlet temperature, in combination with a heat of reaction between the acid gases and the solvent stream; and

instruct the controller to adjust operating parameters corresponding to the gas processing system based on the determined amount of acid gases absorbed by the solvent stream within each co-current contacting system.

13. The computing system of claim 12, wherein the acid gases comprise H₂S and CO₂, and wherein the non-transitory, computer-readable storage medium comprises code configured to direct the processor to:

5 instruct the controller to measure an amount of H₂S absorbed by the solvent stream within each co-current contacting system via an H₂S analyzer positioned downstream of each co-current contacting system; and

10 determine an amount of CO₂ absorbed by the solvent stream within each co-current contacting system by subtracting the amount of H₂S absorbed by the solvent stream from the amount of acid gases absorbed by the solvent stream for each co-current contacting system.

14. The computing system of claim 12 or 13, wherein the non-transitory, computer-readable storage medium comprises code configured to direct the processor to instruct the
15 controller to adjust the operating parameters corresponding to the gas processing system by dynamically adjusting a reboiler duty of the regenerator based on fluctuations in the amount of acid gases absorbed by the solvent stream within each co-current contacting system.

15. The computing system of any of claims 12 to 14, wherein the non-transitory,
20 computer-readable storage medium comprises code configured to direct the processor to instruct the controller to adjust the operating parameters corresponding to the gas processing system by dynamically adjusting at least one of the solvent flow rate or a solvent temperature based on fluctuations in the amount of acid gases absorbed by the solvent stream within each co-current contacting system.

25 16. The computing system of claim 15, wherein the non-transitory, computer-readable storage medium comprises code configured to direct the processor to instruct the controller to dynamically adjust the at least one of the solvent flow rate or the solvent temperature to provide for enhanced H₂S removal from the sour feed gas stream.

17. The computing system of any of claims 12 to 16, wherein the non-transitory, computer-readable storage medium comprises code configured to direct the processor to instruct a controller corresponding to a downstream process to adjust operating parameters corresponding to the downstream process based on the determined amount of acid gases absorbed by the solvent stream within each co-current contacting system of the gas processing system.

18. The computing system of claim 17, wherein the downstream process comprises a downstream acid gas enrichment process, and wherein the non-transitory, computer-readable storage medium comprises code configured to direct the processor to instruct the controller corresponding to the downstream acid gas enrichment process to increase a solvent flow rate corresponding to the downstream acid gas enrichment process in response to fluctuations in the amount of acid gases absorbed by the solvent stream within each co-current contacting system of the gas processing system.

19. The computing system of any of claims 12 to 18, wherein the non-transitory, computer-readable storage medium comprises code configured to direct the processor to instruct the controller to adjust the operating parameters corresponding to the gas processing system by:

monitoring the amount of acid gases absorbed by the solvent stream within each co-current contacting system to determine whether a total amount of absorbed acid gases

exceeds a predetermined acid gas loading limit; and

if the total amount of absorbed acid gases exceeds the predetermined acid gas loading limit, increasing the solvent flow rate to avoid operating at conditions that are favorable for corrosion.

20. A non-transitory, computer-readable storage medium, comprising program instructions that are executable by a processor to cause the processor to:

instruct a controller of a gas processing system to:

contact a sour feed gas stream comprising acid gases with a solvent stream within co-current contacting systems of the gas processing system to generate a

sweetened gas stream and a rich solvent stream comprising absorbed acid gases;

remove the absorbed acid gases from the rich solvent stream within a regenerator of the gas processing system to regenerate the solvent stream;

5 measure a gas flow rate for the sour feed gas stream and a solvent flow rate for the solvent stream via corresponding flow meters within the gas processing system;

measure at least one of a liquid inlet temperature or a gas inlet temperature for each co-current contacting system via a corresponding temperature sensor

10 positioned upstream of each co-current contacting system; and

measure at least one of a liquid outlet temperature or a gas outlet temperature for each co-current contacting system via a corresponding temperature sensor positioned downstream of each co-current contacting system;

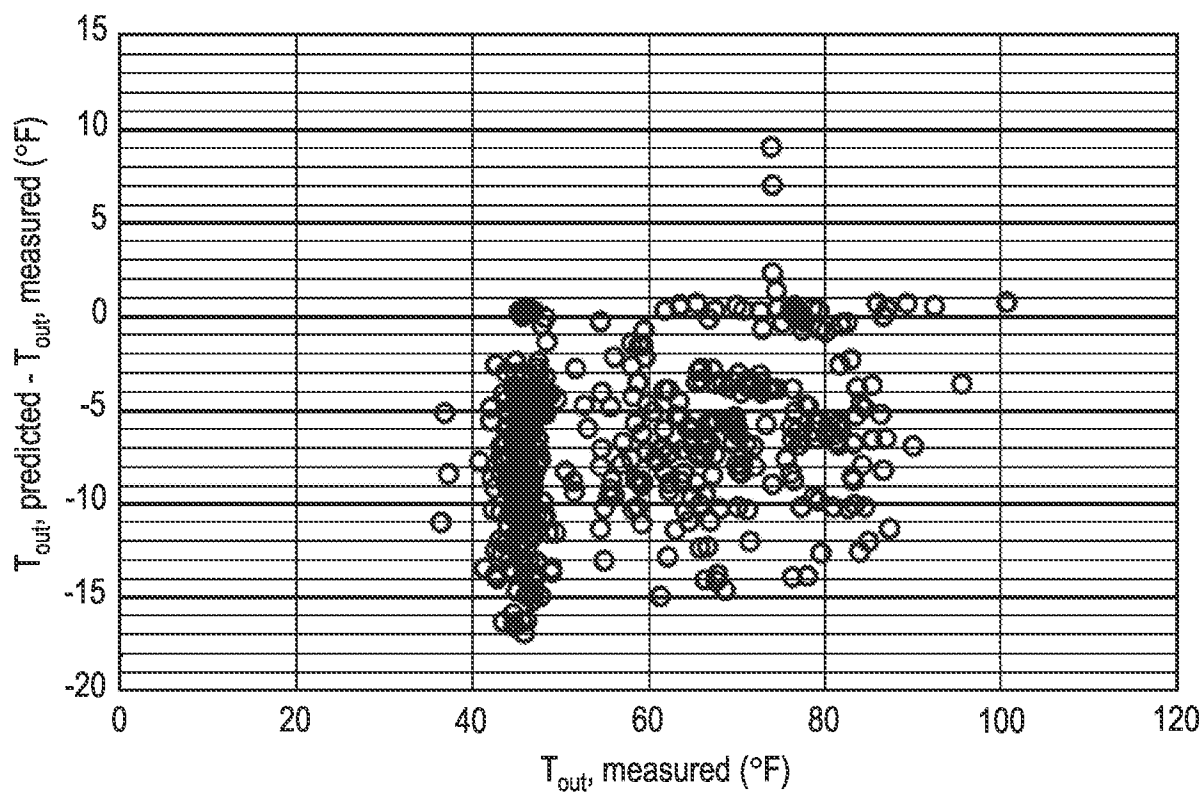
determine an amount of acid gases absorbed by the solvent stream within each co-current

15 contacting system based on the gas flow rate, the solvent flow rate, the at least one of the liquid inlet temperature or the gas inlet temperature, and the at least one of the liquid outlet temperature or the gas outlet temperature, in combination with a heat of reaction between the acid gases and the solvent stream; and

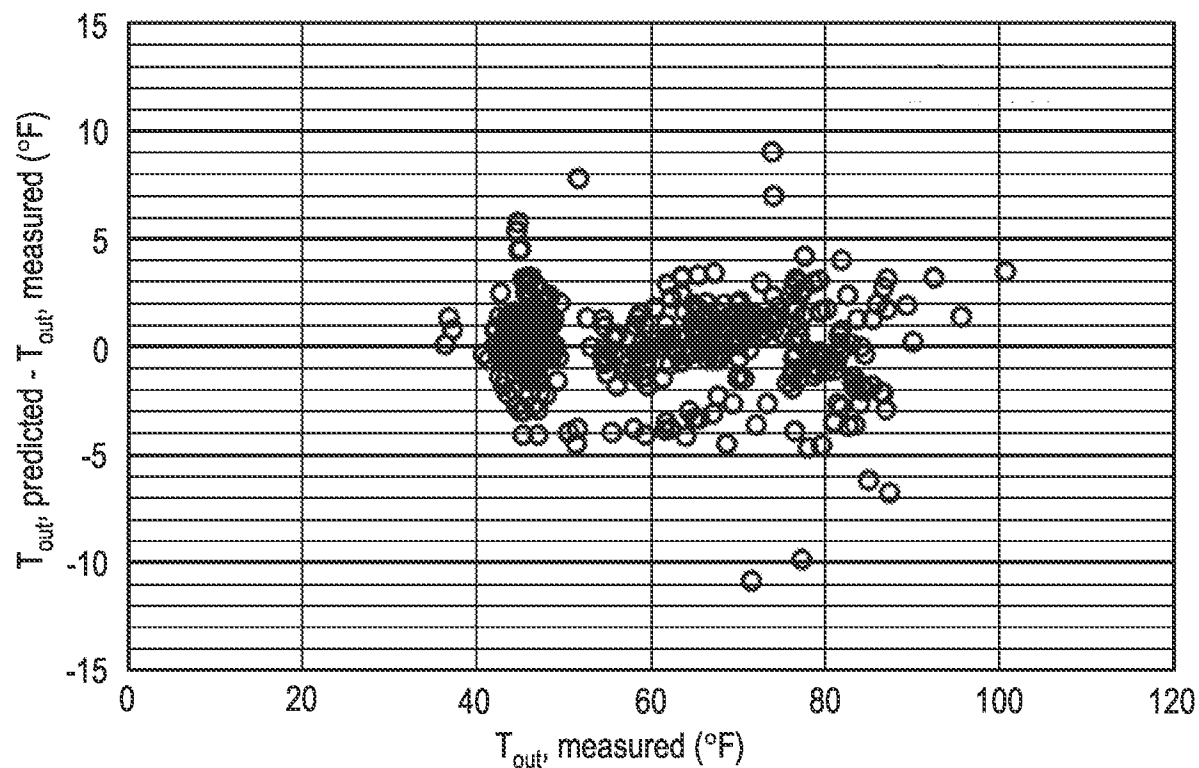
instruct the controller to adjust operating parameters corresponding to the gas processing

20 system based on the determined amount of acid gases absorbed by the solvent stream within each co-current contacting system.

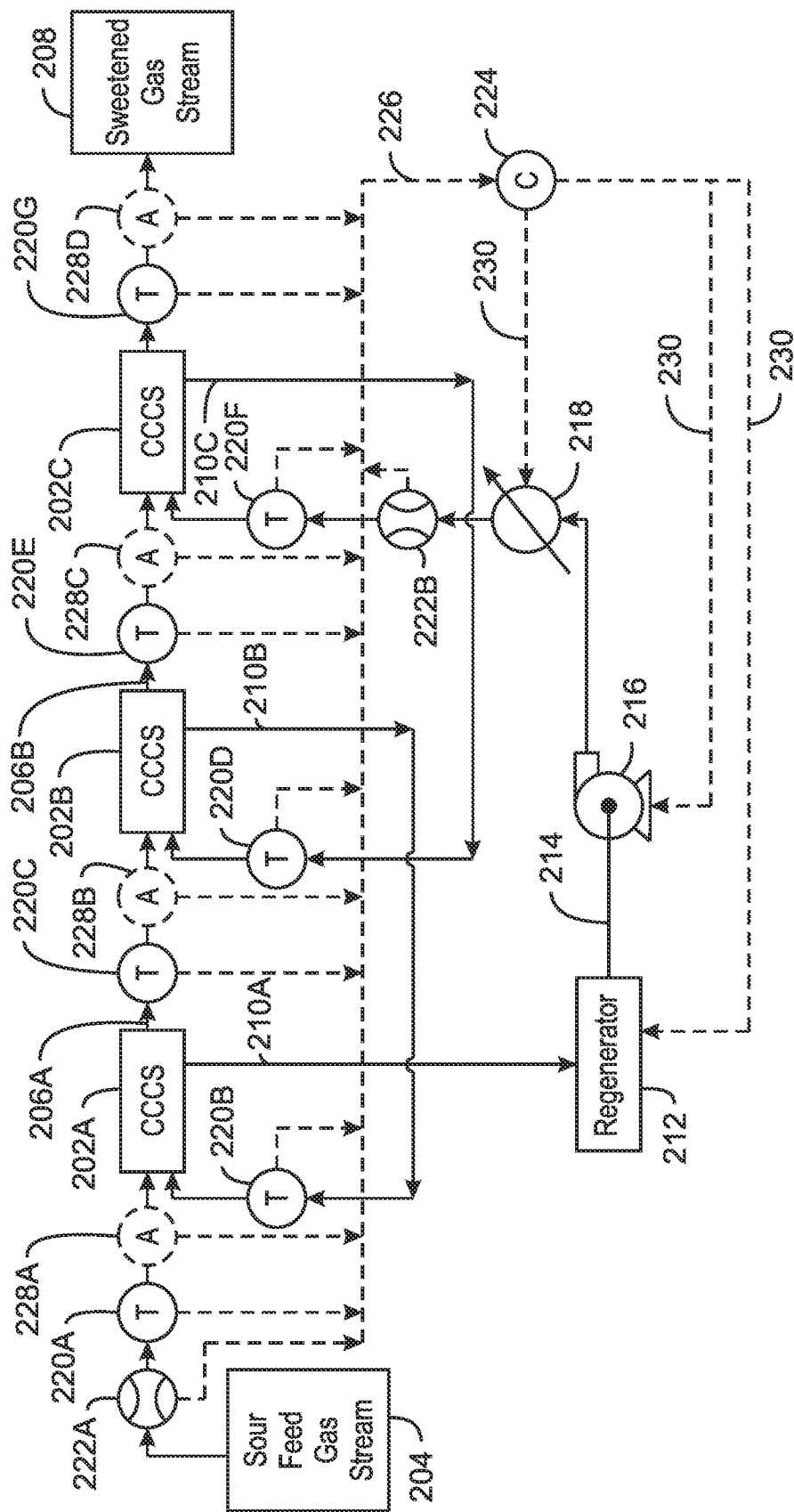
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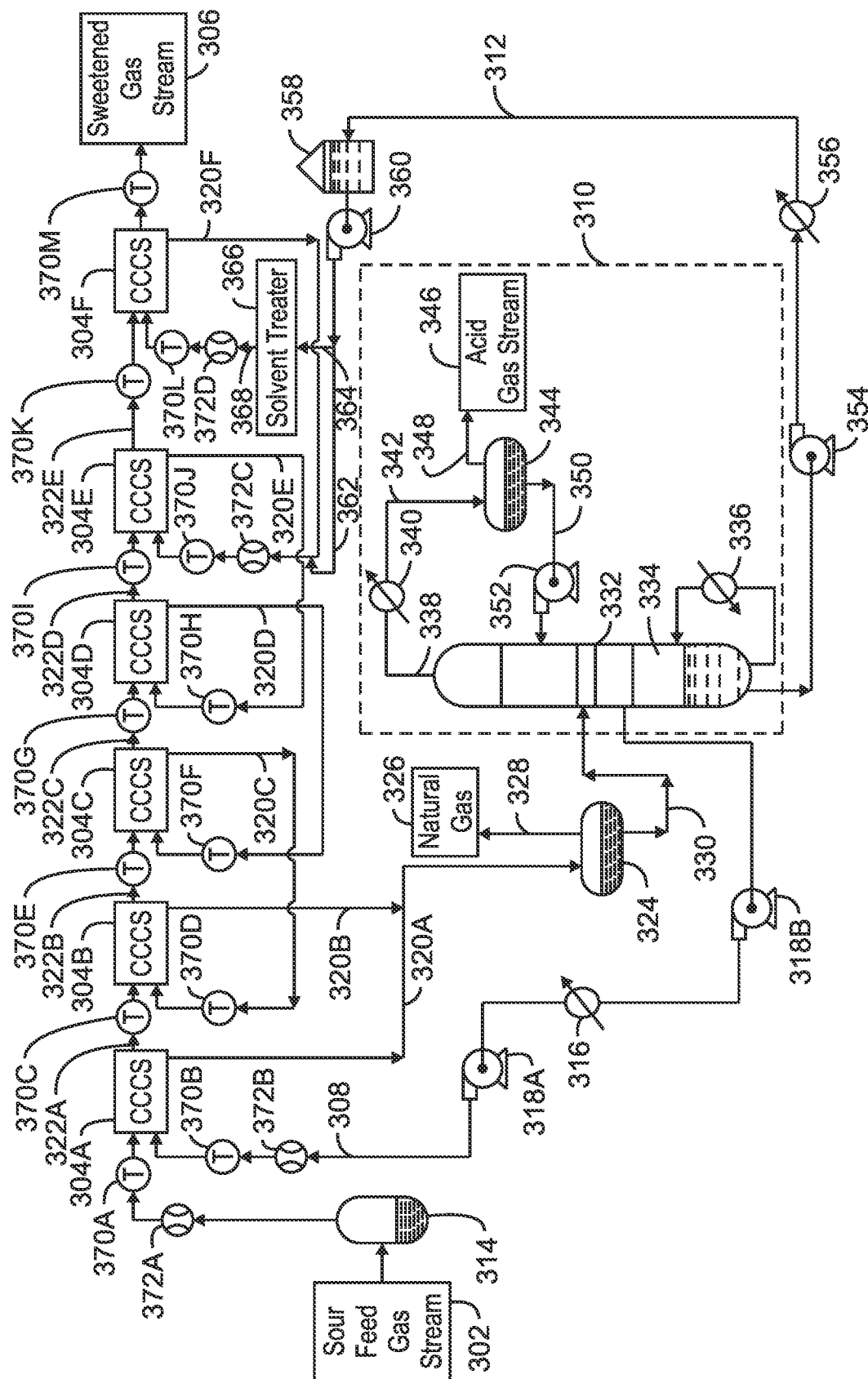
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FIG. 1A



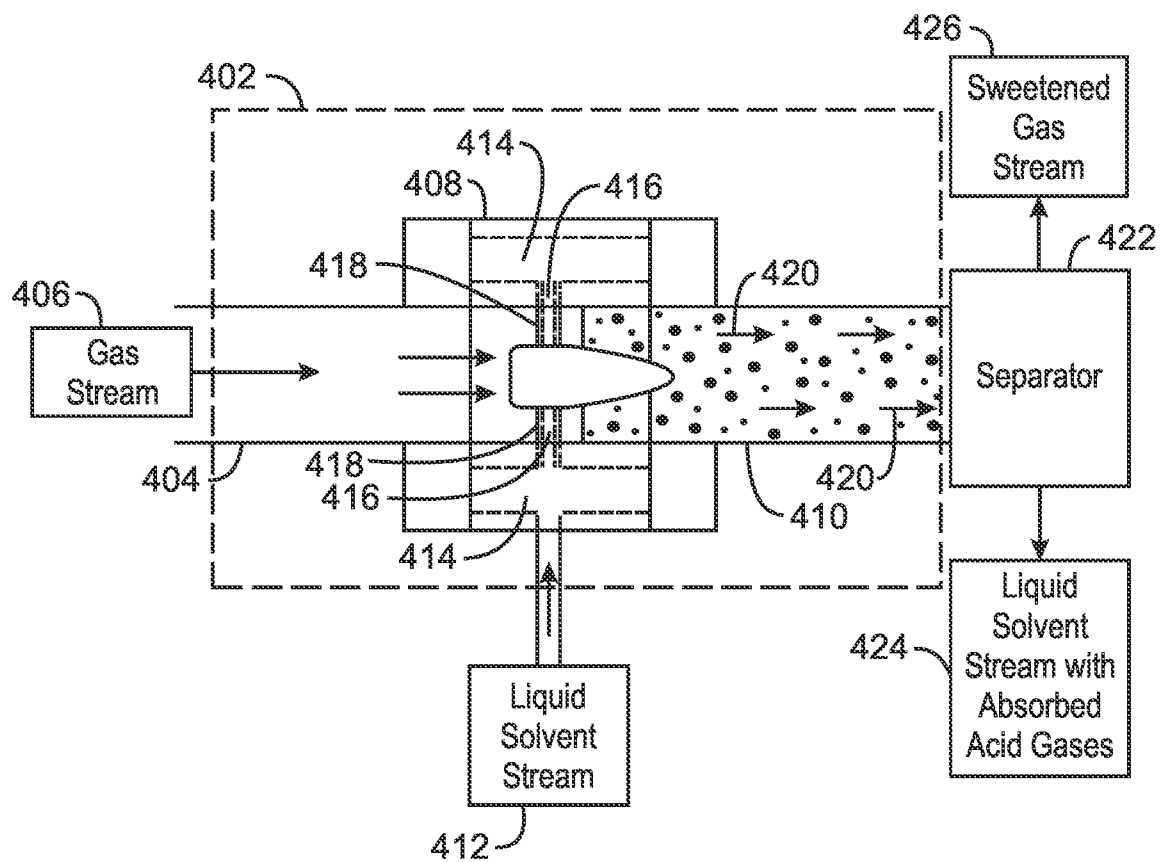
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FIG. 1B



200
FIG. 2

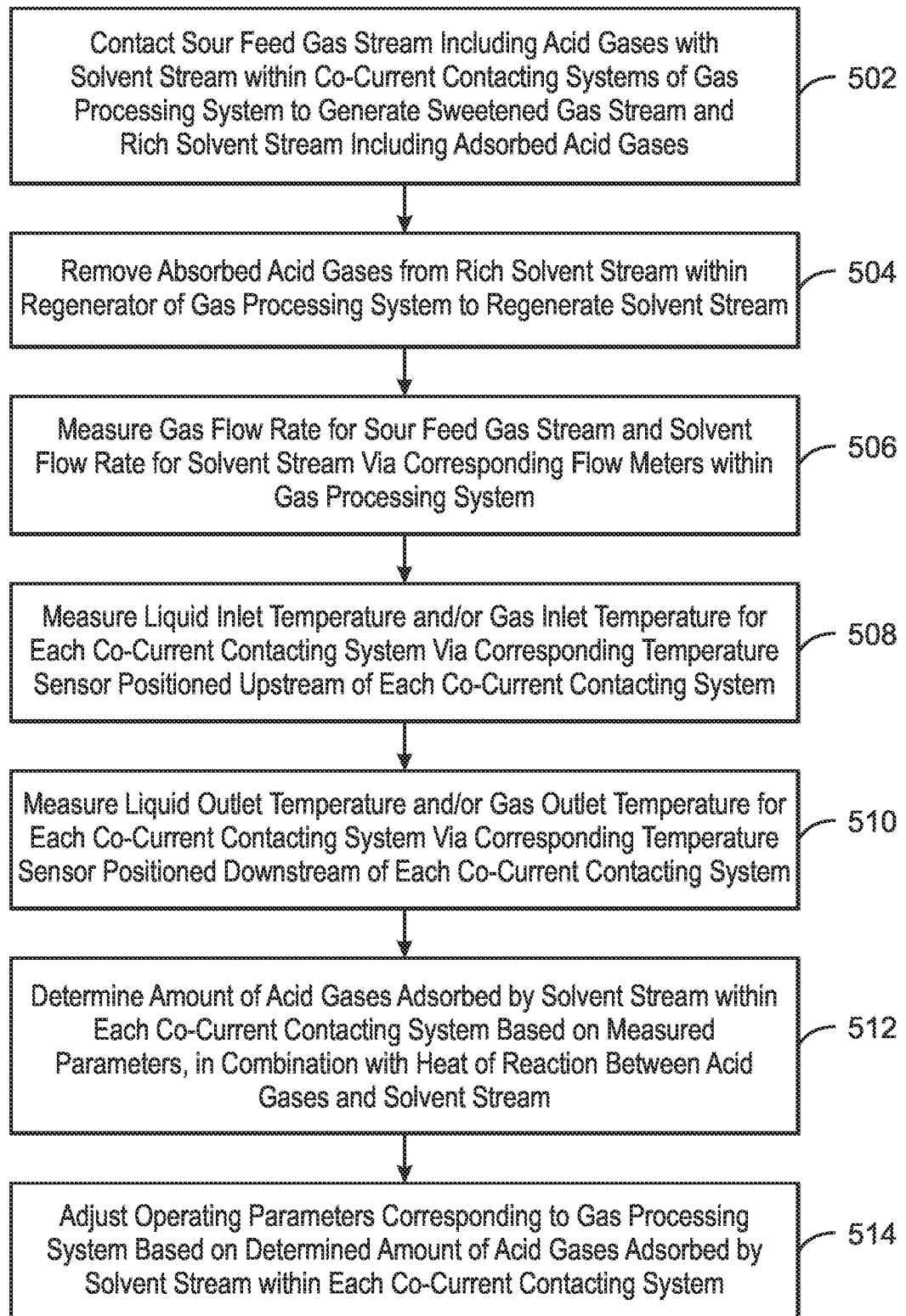

$$\frac{3}{\frac{300}{1000000}}$$

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400
FIG. 4

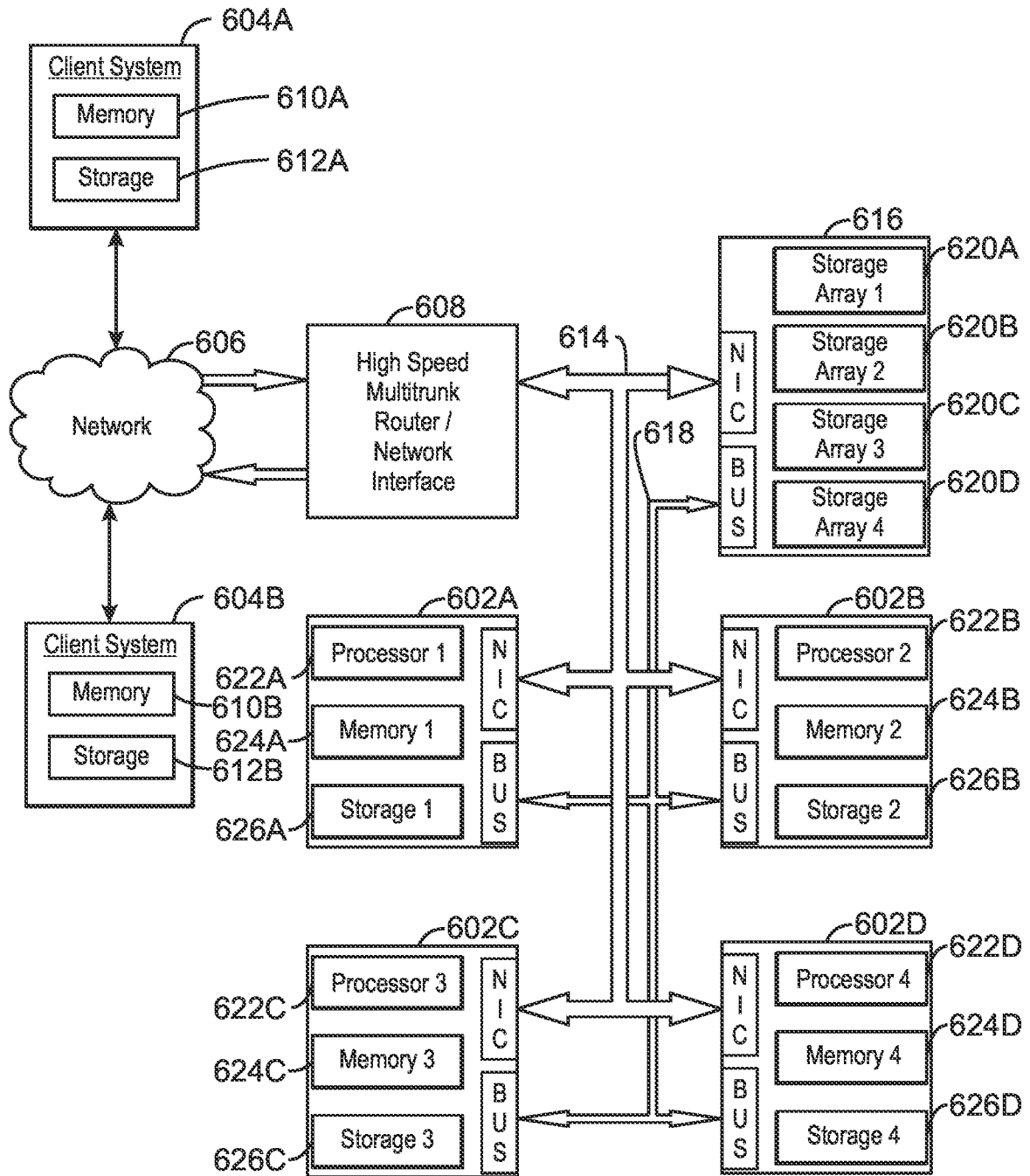
5/7



500

FIG. 5

6/7



600
FIG. 6

7/7

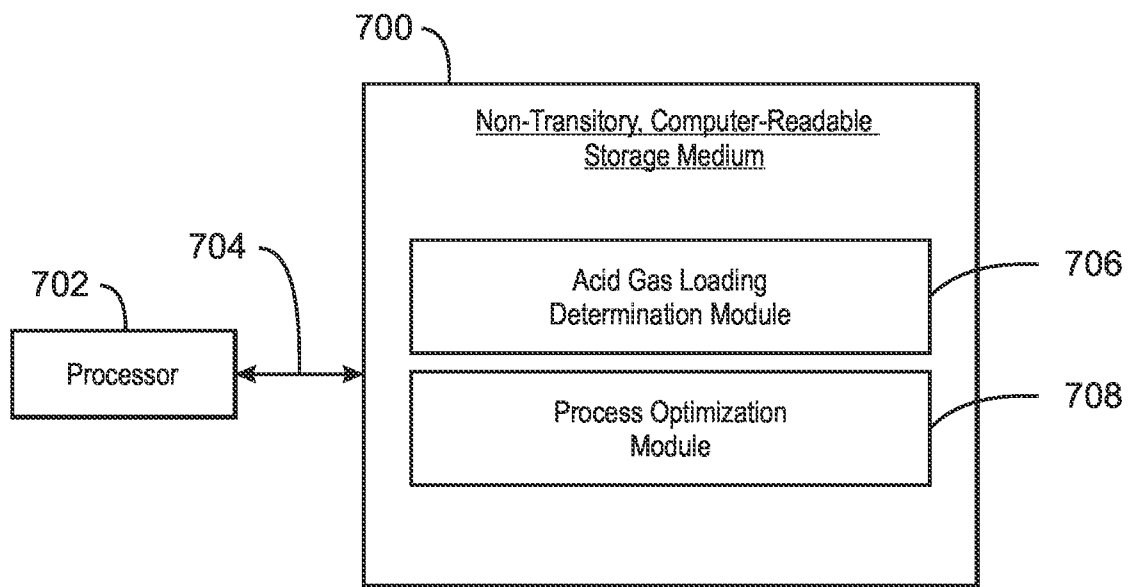


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2022/070087

A. CLASSIFICATION OF SUBJECT MATTER
INV. B01D53/14 C10L3/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B01D C10L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2018/071674 A1 (FREEMAN STEPHANIE A [US] ET AL) 15 March 2018 (2018-03-15) paragraphs [0017], [0048], [0087] - [0090]; claims 1-4; figure 4 -----	1, 5-12, 15-20 3, 4, 14 2, 13
Y	US 2019/054415 A1 (MAHER DAVID W [US] ET AL) 21 February 2019 (2019-02-21) paragraphs [0035] - [0048] -----	3, 4, 14
A	WO 2020/106396 A1 (EXXONMOBIL UPSTREAM RES CO [US]) 28 May 2020 (2020-05-28) claims 12-33; figures 1-3 -----	1, 2, 5-13, 15-20
A	AU 2016 355 446 A1 (EXXONMOBIL UPSTREAM RES CO) 26 April 2018 (2018-04-26) paragraphs [0050] - [0075], [0110]; figure 2 -----	1-11
		1-12, 20

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

25 April 2022

Date of mailing of the international search report

12/05/2022

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2022/070087

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2018071674 A1	15-03-2018	AU 2017326964 A1	28-02-2019
		BR 112019002881 A2	21-05-2019
		CA 3035598 A1	22-03-2018
		CN 109715267 A	03-05-2019
		EP 3512620 A1	24-07-2019
		JP 2019532802 A	14-11-2019
		SG 11201900723Y A	29-04-2019
		US 2018071674 A1	15-03-2018
		WO 2018052521 A1	22-03-2018
US 2019054415 A1	21-02-2019	AU 2018322435 A1	20-02-2020
		BR 112020002881 A2	28-07-2020
		CA 3073036 A1	28-02-2019
		CL 2020000430 A1	26-06-2020
		CN 110997108 A	10-04-2020
		EP 3672710 A1	01-07-2020
		KR 20200042498 A	23-04-2020
		SG 11202000722P A	30-03-2020
		US 2019054415 A1	21-02-2019
		WO 2019040305 A1	28-02-2019
WO 2020106396 A1	28-05-2020	BR 112021008013 A2	03-08-2021
		EP 3883670 A1	29-09-2021
		JP 2022513039 A	07-02-2022
		SG 11202104587V A	29-06-2021
		WO 2020106396 A1	28-05-2020
AU 2016355446 A1	26-04-2018	AR 106746 A1	14-02-2018
		AU 2016355446 A1	26-04-2018
		BR 112018006346 A2	16-10-2018
		CA 3001479 A1	26-05-2017
		CN 108348846 A	31-07-2018
		EP 3377196 A1	26-09-2018
		JP 6818760 B2	20-01-2021
		JP 2019505378 A	28-02-2019
		SG 11201802776T A	28-06-2018
		US 2017145803 A1	25-05-2017
		WO 2017087056 A1	26-05-2017