(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
21 September 2023 (21.09.2023)

WIPO | PCT

(10) International Publication Number
WO 2023/177742 A1

(51) International Patent Classification:
C01C 1/24 (2006.01) *B01D 53/14* (2006.01)
C01B 17/64 (2006.01)

(21) International Application Number:
PCT/US2023/015297

(22) International Filing Date:
15 March 2023 (15.03.2023)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/320,956 17 March 2022 (17.03.2022) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:
— *with international search report (Art. 21(3))*
— *with amended claims and statement (Art. 19(1))*

(54) **Title:** PROCESS FOR PRODUCING FERTILIZER FROM A BIOGAS STREAM

(57) **Abstract:** A process for producing organic fertilizers involves using a waste ammonia stream to capture sulfur dioxide from the oxidation of sulfur or a gas containing sulfur dioxide to make an ammonium bisulfite/sulfite solution. The sulfite solution is used to scrub hydrogen sulfide out of a biogas or other gas stream. The resulting products contain ammonium thiosulfate and ammonium bisulfite/sulfite.

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PROCESS FOR PRODUCING FERTILIZER FROM A BIOGAS STREAM

FIELD OF THE INVENTION

[0001] The present invention relates to systems and processes for removing hydrogen sulfide from a gas stream. In particular, the present invention relates to a system for removing hydrogen sulfide from a biogas stream while producing ammonium thiosulfate, a high value-added product, useful as a fertilizer.

DESCRIPTION OF THE RELATED ART

[0002] Anaerobic digestion is a sequence of processes by which microorganisms break down biodegradable organic material and waste in the absence of oxygen to produce biogas and digestate. Anaerobic digestion can take place in a sealed pond or a reactor vessel containing complex microbial communities. The process is used for industrial or domestic purposes to manage waste or to produce fuels.

[0003] Biogas is composed of methane (CH_4), which is the primary component of natural gas, at a relatively high percentage (50 to 75 percent), carbon dioxide (CO_2), hydrogen sulfide (H_2S), water vapor, and trace amounts of other gases. Carbon dioxide lowers the heating value of the biogas, and hydrogen sulfide is a highly corrosive pollutant that is extremely toxic and flammable, especially if exposed to the atmosphere. If the biogas stream is to be used for boilers or other local uses, the carbon dioxide may remain in the biogas. Otherwise, the carbon dioxide and hydrogen sulfide can be removed by conventional systems, such as, an amine system. In conventional amine systems, liquid amine is contacted with the biogas causing carbon dioxide and hydrogen sulfide to be absorbed by the amine. Then the amine is regenerated by stripping carbon dioxide and hydrogen sulfide out, leaving a lean amine that is suitable for recontacting with the biogas.

Stripping may be accomplished by heat input or pressure decrease. The degree to which carbon dioxide and hydrogen sulfide is stripped from a rich amine depends on the amount of heat used or the amount the pressure is decreased. Over stripping, or removing more carbon dioxide and hydrogen sulfide than necessary to regenerate amine, may result in an energy penalty. Conversely, government regulations limit the maximum amount of sulfur dioxide that may be generated when gas is combusted, and under stripping, or removing too little acid gas, can result in environmental penalties or unsaleable gas. Lastly, removing sulfur dioxide is a corrosive process and produces an undesirable waste stream.

[0004] Ammonia (NH_3) in the digestate can also be problematic. A common means of disposal is to air strip NH_3 out of the digestate for reaction with sulfuric acid (H_2SO_4) to produce an ammonium sulfate (AMS) solution. The low nutrient value of the ammonium sulfate produced and the need to store large quantities of the sulfuric acid and liquid ammonium sulfate makes this process uneconomical.

[0005] Therefore, there is a need to convert such lower value-added ammonia streams into higher value-added products, such as organic fertilizers, so that they can be a source of revenue and can increase the environmental benefit of a biogas project or plant.

SUMMARY OF THE INVENTION

[0006] According to one or more embodiments of the present invention, a higher value-added ammonium thiosulfate (ATS) solution is produced. ATS can be beneficially used as a fertilizer. The process utilizes an anaerobic digester produced ammonia-containing gas stream and a non-hydrocarbon sourced gas to remove hydrogen sulfide from the biogas. Since the ammonia used to produce the ATS solution is obtained from an organically certified process using an anaerobic digester, the ATS solution can also classified and marketed as an organic product. Furthermore, the product and process are organic since fossil fuel is not consumed.

[0007] Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and the specific embodiment disclosed might

be readily utilized as a basis for modifying or redesigning the structures for carrying out the same purposes as the invention. The foregoing has outlined rather broadly several aspects of the present invention in order that the detailed description of the invention that follows may be better understood.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIGURE 1 depicts one non-limiting embodiment of a system for removing hydrogen sulfide from a biogas stream and producing ammonium thiosulfate.

DETAILED DESCRIPTION

[0009] The present invention relates to systems and processes for removing hydrogen sulfide from a biogas/sour biogas stream. In particular, the present invention relates to a system for removing hydrogen sulfide from a biogas stream while converting low valued ammonia streams into a high valued organic fertilizer, such as, ATS. One example of such a system is depicted in **Fig. 1**.

[0010] It is noted that the components of the embodiment shown in **Fig. 1** are not necessarily drawn to scale and emphasis is instead placed upon clearly illustrating the principles of the present invention.

[0011] The term "one embodiment" refers to one example of a method or system that can carry out the inventive process described herein. However, it will be apparent to one of ordinary skill in the art that the inventive concepts within the disclosure may be practiced without the specifically described features but be accomplished with a number of alternative components or methods.

[0012] As used herein, the terms "column" and "contact zone" can include any combination of towers, columns, trays, vessels, pumps, valves, control systems, and any other equipment known in the art useful in contacting liquids and gases.

[0013] An embodiment of the process described herein involves air stripping an aqueous ammonia-containing waste stream from the digestate (produced during anaerobic digestion) at a predetermined temperature to saturate the air with ammonia. The ammonia

content in the resulting gas stream can be based on the amount of water in the anaerobic digester (not shown), which is further dependent on the technology, or combination of technologies, used to produce the ammonia. The ammonia content is typically low and can range from 1,500 ppm to 5,000 ppm.

[0014] According to another embodiment, an organic fertilizer is produced from two contaminated streams from anaerobic digestion. This involves passing an aqueous ammonia-containing stream from the anaerobic digester through a filter to remove solids followed by boiling ammonia and hydrogen sulfide (contained in the biogas produced during the anerobic digestion) out of the digestate using a sour water stripper. The process liberates the contaminated ammonia and hydrogen sulfide streams by heating the filtered digestate and subsequently condensing the gases in a cooler aqueous solution.

[0015] The ammonia-containing gaseous stream produced from the digestate is thus advantageously precluded from being discharged or reused in the digester.

[0016] As shown in **Fig. 1**, an ammonia-containing gas stream **10**, produced from the digestate and having a relatively low concentration of ammonia, can be introduced into a first Column **100**. A stream of sulfur dioxide (SO_2) gas **20** can be added near a first contact zone **101** of Column **100**. The ammonia-containing gas stream **10** is circulated through an aqueous solution rich in bisulfite ions near a second contact zone **102**. The sulfur dioxide stream **20** can be used to control the sulfite to bisulfite ratio in the circulating solution.

[0017] The sulfur dioxide gas stream **20** can be obtained, for instance, from the oxidation of sulfur on site, or it can be a purchased stream of sulfur dioxide. In general, any gas stream rich in sulfur dioxide can be used as stream **20**.

[0018] The sulfur dioxide is quickly reacted out of Column **100** by maintaining a relatively high pH in the first contact zone **101**. A relatively lower pH is maintained in the second contact zone **102** in order to limit the ammonia or sulfur dioxide gases from escaping into the vented gas stream **30**. Ammonia, sulfur dioxide, and water react in Column **100** to produce a mixture of ammonium bisulfite (ABS or NH_4HSO_3) and diammonium sulfite (DAS or $(NH_4)_2SO_3$) in an aqueous solution. The ratio of ABS and

DAS is dependent on the pH of the solution used in the contact zones of Column **100**. This ABS/DAS aqueous solution can be sold or used as an intermediate in other processes.

[0019] The pH of the two contact zones **101**, **102** can be maintained between 4.5 and 7.8, and preferably between 5.5 and 6.5 (where it is again noted that the pH of contact zone **101** is higher than the pH of contact zone **102**), to absorb ammonia and to minimize the vapor pressure of sulfur dioxide and ammonia in the solution. The vapor pressure can be further reduced by cooling the circulating solution.

[0020] In an alternative embodiment, the contact zones in Column **100** can be reversed such that sulfur dioxide is introduced into the second contact zone while the ammonia-containing stream is introduced into the first contact zone. The respective pH values of the contact zones are accordingly adjusted to limit sulfur dioxide and ammonia emission from vented gas stream **30**.

[0021] The resulting aqueous solution **40** can exit from Column **100** from the bottom of the column as a liquid mixture of ABS, DAS, and water (also referred to herein as "ABS/DAS solution"). A portion of this solution is taken to a second Column **200** and the remainder is circulated back through the contact zones of Column **100** to add more aqueous ammonia and a sulfite rich solution to the process flow. Simultaneously, the liquid stream re-contacts with sulfur dioxide to substantially increase the concentration of sulfite in solution. The pH of the recirculated or recycled solution is adjusted to below 7.8, with a preferred pH below 6.3, utilizing sulfur dioxide, to further scrub the solution of residual ammonia.

[0022] In one embodiment the ABS/DAS solution exiting Column **100** can be used to scrub hydrogen sulfide out of the biogas produced during anaerobic digestion in a contact device to produce ammonium thiosulfate (ATS) which can be used as a fertilizer. The scrubbing can be conducted at a desired pressure, leaving carbon dioxide with the methane in the biogas.

[0023] In one or more embodiments, an amine system or other conventional technology is used to remove hydrogen sulfide from a small biogas stream, such that the treated biogas that can be used with commercially produced natural gas. The process uses

waste ammonia to capture sulfur dioxide from a burner or as purchased material making an ammonium sulfite solution to subsequently scrub hydrogen sulfide (H_2S) out of a biogas or other gas stream. Any remaining carbon dioxide is then vented to the atmosphere.

[0024] As shown in **Fig. 1**, a portion of the ABS/DAS solution **40** is pumped to the second Column **200**. There the solution is contacted with a sour biomethane gas **50** (or biogas) that is introduced into Column **200**. The biogas **50** can be routed/obtained from the anaerobic digester (or another organic source).

[0025] According to one or more embodiments, Column **200** can include multiple contact zones. As shown, in **Fig. 1**, Column **200** includes three contact zones, namely, **201**, **202** and **203**. In contact zone **201**, the pH is maintained at a higher value than the pH in contact zones **202** and **203** to quickly scrub H_2S out of the biogas. The pH in contact zone **202** is intentionally maintained at a lower value than that in contact zone **201** to limit ammonia, H_2S or SO_2 from escaping into the biogas stream. In contact zone **203**, water, that is preferably chilled, is contacted with the gas to remove any residual ammonia, H_2S or SO_2. Chilled water is further beneficial in lowering the vapor pressure and enhances the capture of ammonia, H_2S, and SO_2. In an embodiment, the pH of the three contact zones is around 4.5 to 6.3.

[0026] Since the outflow solution **40** is aqueous and comprises ammonium bisulfite and ammonium sulfite in their ionic form, the hydrogen sulfide contained in the biogas **50** reacts with the ABS/DAS solution to produce an effluent stream of ammonium thiosulfate (ATS) liquid that can exit from the bottom of the second contact Column **200** as ATS stream **60**. The effluent ATS liquid **60** can be transported to a storage unit (or storage area) **300**.

[0027] Advantageously, carbon dioxide is non-reactive with the ammonium sulfite and ammonium bisulfite in the outflow solution. Therefore, in contrast to most physical and alkaline solvents, the outflow solution **40** selectively captures hydrogen sulfide and rejects the carbon dioxide present in the biogas. Overhead gas stream **70** that leaves the second contact Column **200** has had hydrogen sulfide substantially removed but it can still contain carbon dioxide.

[0028] In an exemplary embodiment, the process further involves recycling ATS to beneficially control the nitrogen to sulfur ratio in Contact Zone **201** and to continually enrich the ATS rich liquid in the storage unit **300**. The enriched ATS rich liquid can be taken from the storage area **600** to be sold directly as a high-value added fertilizer **80.**

[0029] A heat exchanger (not shown) can be used to regulate the temperature in Column **200**, enhance reaction rates and reduce the amount of hydrogen sulfide reaching contact zone **203**. Due to elevated temperature in Column **200**, contact zone **203**, located near the top of Column **200**, can be cooled by introducing chilled water. The chilled water lowers the vapor pressure of the gases, thereby removing any residual ammonia, hydrogen sulfide or sulfur dioxide. Importantly, the stoichiometric ratio of ammonia to hydrogen sulfide is maintained in slight excess of 1:1 to convert all the hydrogen sulfide to ATS in Column **200** and to provide a buffer against any excess hydrogen sulfide in the solution.

[0030] In one or more embodiments, the water routed into contact zone **203** has a low chloride content, in the range of 0 to 250 ppm, to prevent any stress corrosion cracking in the stainless-steel portions of the second column.

[0031] In an optional embodiment, a portion of the ATS rich stream **60** can be routed to Column **100** to reduce the vapor pressure of sulfur dioxide and ammonia in Column **100** and to increase the ATS content in the circulating solution.

[0032] In one or more embodiments, at least two of the contact zones/stages in Column **200** may be combined into one. This can result in cost savings where high removal of hydrogen sulfide is achievable but not essential.

[0033] A person skilled in the art would understand that the number of contact zones in the second column (Column **200**), the gas velocity, and the recycle rate can be easily manipulated to adapt to various reaction kinetics for the absorption of hydrogen sulfide.

[0034] The foregoing describes one or more embodiments for producing organic fertilizers. Advantageously, the embodiments of the invention can use contaminated gaseous streams (containing ammonia and hydrogen sulfide) from an anaerobic digestor to produce a high value added product, namely, ammonium thiosulfate. The present

invention, therefore, utilizes an anaerobic digester produced ammonia and a non-hydrocarbon sourced gas to remove hydrogen sulfide from biogas. While many fluid thiosulfate fertilizers are available, ammonium thiosulfate (ATS) is the most widely used fluid fertilizer that contains sulfur. It contains sulfur dioxide, elemental sulfur, and aqueous ammonia in a liquid format that serves as an effective source of sulfur and nitrogen to crops. The present invention produces significant amounts of an organic ATS fertilizer that meets the Principles of Organic Agriculture and can be used for commercial organic agriculture.

[0035] Organic fertilizers are fertilizers that are produced from natural sources as opposed to synthetic fertilizers that are man-made, inorganic fertilizers. Organically derived fertilizers stimulate beneficial soil microorganisms and improve the structure of the soil. Soil microbes play a key role in converting organic fertilizers into soluble nutrients that can be absorbed by plants at a rate they can use, thereby promoting stronger root growth for better disease and insect resistance. Furthermore, organic fertilizers that meet the Principles of Organic Agriculture can be used for commercial organic agriculture. ATS in particular inhibits the conversion of ammonia in the soil to nitrate thereby allowing the applied ammonia based fertilizer to be better utilized by the plant.

[0036] While the foregoing describes various embodiments of the invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof. The scope of the invention is determined by the claims that follow. The invention is not limited to the described embodiments, versions or examples, which are included to enable a person having ordinary skill in the art to make and use the invention when combined with information and knowledge available to the person having ordinary skill in the art.

CLAIMS

1. A process for producing an organic fertilizer, comprising:

introducing a stream of sulfur dioxide into a first column;

routing an ammonia-containing gas stream into the first column, wherein the ammonia-containing gas stream is circulated through an aqueous solution containing bisulfite ions in the first column, and further wherein the ammonia-containing gas stream reacts with the sulfur dioxide and aqueous solution containing bisulfite ions to produce an aqueous solution comprising ammonium bisulfite and diammonium sulfite;

routing a portion of the aqueous ammonium bisulfite and diammonium sulfite solution to a second column;

introducing a biogas stream into the second column, wherein the biogas stream comprises hydrogen sulfide; and

contacting the routed aqueous ammonium bisulfite and diammonium sulfite solution and biogas stream in the second column to substantially scrub the hydrogen sulfide from the biogas stream and produce an effluent stream containing aqueous ammonium thiosulfate.

2. The process according to Claim 1, wherein the ammonia-containing gas stream is obtained from an anaerobic digestate.

3. The process according to Claim 1, wherein the ammonia-containing gas stream is produced from a sour water stripper or steam stripper.

4. The process according to Claim 1, wherein the first column contains at least two contact zones, and wherein the sulfur dioxide is introduced near a first contact zone and the ammonia-containing gas stream is introduced near a second contact zone.

5. The process according to Claim 4, further comprising maintaining a higher pH in the first contact zone and a lower pH in the second contact zone.

6. The process according to Claim 5, wherein the pH of the first and second contact zones is in the range of 5.5 to 6.5.

7. The process according to Claim 1, wherein another portion of the aqueous ammonium bisulfite and diammonium sulfite solution is circulated back into the first column.

8. The process according to Claim 1, wherein the biogas is produced during an anaerobic digestion reaction, and wherein the biogas further comprises methane and carbon dioxide.

9. The process according to Claim 1, wherein the second column comprises a plurality of contact zones.

10. The process according to Claim 9, wherein the pH of each contact zone in the second column is around 4.5 to 6.3.

11. The process according to Claim 9, wherein the second column includes three contact zones, and wherein the pH of a first contact zone in the second column is maintained at a higher value than the pH in the second and third contact zones to quickly scrub hydrogen sulfide out of the biogas stream.

12. The process according to Claim 11, wherein chilled water is circulated into a third contact zone.

13. The process according to Claim 12, wherein the chilled water has a low chloride content to prevent corrosion of the col.

14. The process according to Claim 1, wherein a portion of the aqueous ammonium thiosulfate is recirculated through the second column.

15. The process according to Claim 14, wherein another portion of the aqueous ammonium thiosulfate is routed to a storage unit.

16. The process according to Claim 1, wherein a stoichiometric excess of ammonia to hydrogen sulfide is maintained in the second column.

17. The process according to Claim 1, wherein the process utilizes an anaerobic digester produced ammonia-containing gas stream and a non-hydrocarbon sourced gas to remove hydrogen sulfide from the biogas.

AMENDED CLAIMS
received by the International Bureau on 08 August 2023 (08.08.2023)

CLAIM AMENDMENTS UNDER PCT ARTICLE 19

1. A process for producing an organic fertilizer, comprising:

introducing a stream of sulfur dioxide into a first column;

routing an ammonia-containing gas stream into the first column, wherein the ammonia-containing gas stream is circulated through an aqueous solution containing bisulfite ions in the first column, and further wherein the ammonia-containing gas stream reacts with the sulfur dioxide and the aqueous solution containing bisulfite ions to produce an aqueous solution comprising ammonium bisulfite and diammonium sulfite;

routing a portion of the aqueous ammonium bisulfite and diammonium sulfite solution to a second column;

introducing a biogas stream into the second column, wherein the biogas stream comprises hydrogen sulfide; and

contacting the routed aqueous ammonium bisulfite and diammonium sulfite solution and biogas stream in the second column to substantially scrub the hydrogen sulfide from the biogas stream and produce an effluent stream containing aqueous ammonium thiosulfate.

2. The process according to Claim 1, wherein the ammonia-containing gas stream is obtained from an anaerobic digestate.
3. The process according to Claim 1, wherein the ammonia-containing gas stream is produced from a sour water stripper or steam stripper.
4. The process according to Claim 1, wherein the first column contains at least two contact zones, and wherein the sulfur dioxide is introduced near a first contact zone and the ammonia-containing gas stream is introduced near a second contact zone.
5. The process according to Claim 4, further comprising maintaining a higher pH in the first contact zone and a lower pH in the second contact zone.
6. The process according to Claim 5, wherein the pH of the first and second contact zones is in the range of 5.5 to 6.5.
7. The process according to Claim 1, wherein another portion of the aqueous ammonium bisulfite and diammonium sulfite solution is circulated back into the first column.

8. The process according to Claim 1, wherein the biogas is produced during an anaerobic digestion reaction, and wherein the biogas further comprises methane and carbon dioxide.
9. The process according to Claim 1, wherein the second column comprises a plurality of contact zones.
10. The process according to Claim 9, wherein the pH of each contact zone in the second column is around 4.5 to 6.3.
11. The process according to Claim 9, wherein the second column includes three contact zones, and wherein the pH of a first contact zone in the second column is maintained at a higher value than the pH in the second and third contact zones to quickly scrub hydrogen sulfide out of the biogas stream.
12. The process according to Claim 11, wherein chilled water is circulated into a third contact zone.
13. The process according to Claim 12, wherein the chilled water has a low chloride content to prevent corrosion of the ~~col~~ column.
14. The process according to Claim 1, wherein a portion of the aqueous ammonium thiosulfate is recirculated through the second column.
15. The process according to Claim 14, wherein another portion of the aqueous ammonium thiosulfate is routed to a storage unit.
16. The process according to Claim 1, wherein a stoichiometric excess of ammonia to hydrogen sulfide is maintained in the second column.
17. The process according to Claim 1, wherein the process utilizes an anaerobic digester produced ammonia-containing gas stream and a non-hydrocarbon sourced gas to remove hydrogen sulfide from the biogas.

AMENDED SHEET (ARTICLE 19)

Statement Under Article 19(1)

The Written Opinion rejects claims 1, 3, 7, 9, 10, and 14-16 as lacking an inventive step over Stercorat in view of Haese. Stercorat discloses production of organic fertilizer comprising ammonium thiosulfate from sulfur dioxide, an ammonia gas stream, and aqueous ammonium sulfite and ammonium bisulfite. Stercorat does not teach introduction of a stream of sulfur dioxide into a first column also containing the ammonia gas stream. Haese teaches a system employing an ammonia containing gas and sulfur dioxide. The combination of Stercorat and Haese, however, does not teach introduction of an ammonia containing gas *and* sulfur dioxide into a *first column*.

Haese discloses two columns, ammonia washer (102) and sulfur dioxide washer (108). An ammonia containing gas stream is introduced into washer 102 via pipeline 101. Col. 3, lines 22-23. Sulfur dioxide is introduced into washer 108 via pipeline 109. Col. 3, lines 40-44. Pipelines between the two washers contain aqueous ammonium sulfite and ammonium bisulfite solutions and not the aforementioned gases. A summary of the chemical reactions shown in Col. 2, line 68 and Col. 3, lines 1-5, indicates that reactants ammonia and sulfur dioxide are clearly limited to their respective washers and do not contact each other.

Stercorat further teaches against introduction of sulfur dioxide into a first column. Specifically, paragraph [0005] discloses that after contacting an ammonium bisulfite and ammonium sulfite solution with sour water stripper gas, "the disadvantage of these processes is the indirect control of the pH of the solutions and thus the reduced absorption efficiency for sulfur dioxide". Paragraph [0017] further illustrates absorption of sulfur dioxide into a solution of ammonium thiosulfate, ammonium bisulfite, and ammonium sulfite is poor and, to improve sulfur recovery, pH should be controlled with addition of ammonia.

Regarding claim 4, Anderson, discloses *two separate* contact zones, 3 and 6 (Figure 1). In Column 3, lines 5-9, contact zones are defined as discrete "towers, columns, trays, ... known in the art useful in facilitating the contact of a liquid and a gas". Anderson does not teach incorporation of at least two contact zones for an ammonia containing gas stream and sulfur dioxide into a single column.

Regarding claim 11, Jiangnan, teaches a column wherein pH of the first contact zone is maintained at a higher value relative to subsequent contact zones in the same column. Jiangnan teaches production of ammonium sulfate that is said to be beneficial as a fertilizer. Col. 1, lines 33-38. Ammonium sulfate does not react with hydrogen sulfide readily to produce the desired ammonium thiosulfate. Jiangnan neither removes dangerous hydrogen sulfide from an ammonia gas stream nor does it produce valuable agricultural fertilizer, ammonium thiosulfate. Due to the pH dependency of the reaction conditions for removing hydrogen sulfide and producing ammonium thiosulfate, it would not be obvious to one of ordinary skill in the art to modify the column of Jiangnan wherein the pH of the first contact zone is maintained at a higher value relative to subsequent contact zones in the same column.

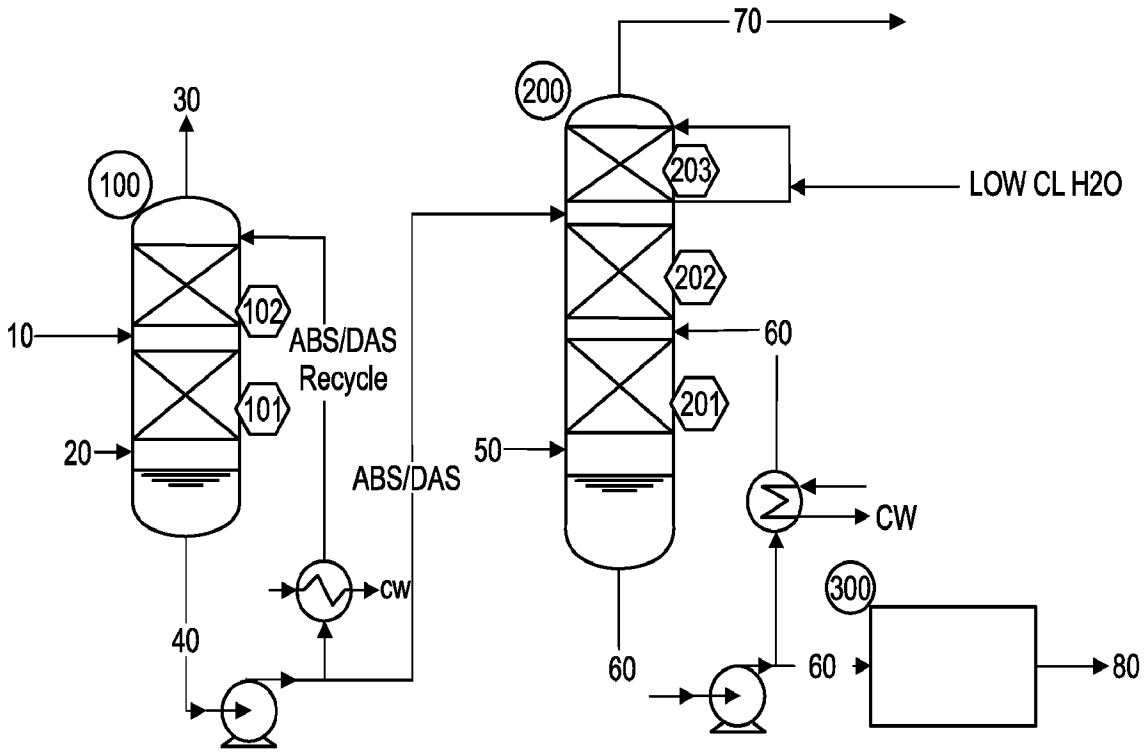

70
200
30
100
203
LOW CL H2O
202
102
10
ABS/DAS
Recycle
60
101
201
20
50
ABS/DAS
CW
cw
300
40
60
60
80

FIG. 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2023/015297

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - INV. - C01C 1/24; C01B 17/64 (2023.01)
ADD. - B01D 53/14 (2023.01)

CPC - INV. - C01C 1/24; C01B 17/64 (2023.02)
ADD. - B01D 53/14 (2023.02)

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)
See Search History document

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

Electronic database consulted during the international search (name of database and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 3 838 381 A1 (STERCORAT HUNGARY KFT) 23 June 2021 (23.06.2021) entire document	1-17
Y	US 4,001,374 A (HAESE) 04 January 1977 (04.01.1977) entire document	1-17
Y	WO 2020/160998 A1 (HALDOR TOPSØE A/S) 13 August 2020 (13.08.2020) entire document	2, 8, 17
Y	US 7,575,732 B2 (ANDERSON et al.) 18 August 2009 (18.08.2009) entire document	4-6
Y	US 10,112,145 B1 (JIANGNAN ENVIRONMENTAL PROTECTION GROUP INC) 30 October 2018 (30.10.2018) entire document	5, 6, 11-13

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
02 May 2023	JUN 08 2023
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Authorized officer Taina Matos Telephone No. PCT Helpdesk: 571-272-4300