



(51) International Patent Classification:

E21B 43/24 (2006.01)

(21) International Application Number:

PCT/US2014/041948

(22) International Filing Date:

11 June 2014 (11.06.2014)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

61/833,505	11 June 2013 (11.06.2013)	US
14/302,004	11 June 2014 (11.06.2014)	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, CZ, DE, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR,
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OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM,
TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM,
ZW.

(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, 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, 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).

Published:

- with international search report (Art. 21(3))
- before the expiration of the time limit for amending the
claims and to be republished in the event of receipt of
amendments (Rule 48.2(h))

(54) Title: STEAM GENERATOR AND CARBON DIOXIDE CAPTURE

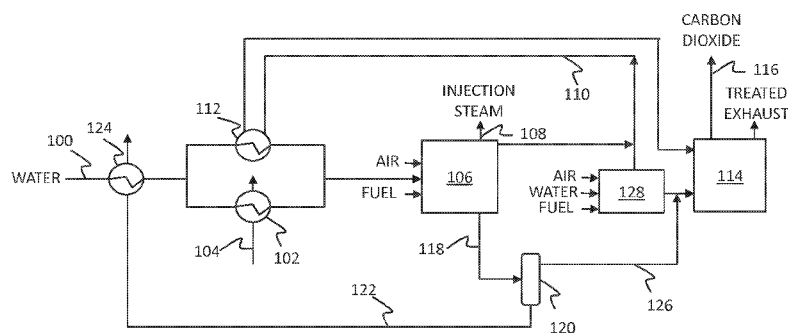


FIG. 1

(57) Abstract: Methods and systems generate steam for injection into a formation in order to facilitate oil recovery and also capture carbon dioxide in a recovery unit that receives flue gas exhaust from such steam generation. The methods and systems integrate various process streams from and to the carbon dioxide recovery unit. Such integration provides resulting benefits associated with efficiency and/or carbon dioxide avoidance.

STEAM GENERATOR AND CARBON DIOXIDE CAPTURE

FIELD OF THE INVENTION

[0001] Embodiments of the invention relate to generating steam and efficient recovery of carbon dioxide from flue gases produced while generating the steam.

BACKGROUND OF THE INVENTION

[0002] Recovery of heavy oil reserves often requires use of steam to heat and mobilize the oil through processes such as steam assisted gravity drainage. Energy intensive steam generators produce the steam and resulting carbon dioxide emissions. Government regulations may make capture and sequestration of the carbon dioxide emissions necessary.

[0003] Scrubbing flue gases of the steam generators with a carbon dioxide absorbing solution like an amine based mixture offers one prior approach for the capture. However, this approach also requires fuel to produce steam used in regenerating the mixture. Additional costs associated with capturing the carbon dioxide further increase expenses limiting economic recovery of the oil.

[0004] Oxy-fuel combustion for steam boilers provides an alternative option for mitigating carbon dioxide emissions since flue gas contains carbon dioxide and water vapor as primary separable constituents. However, the oxy-fuel combustion requires energy intensive cryogenic air separation units limiting actual emission avoidance. Further, recovered carbon dioxide still requires treatment to remove oxygen, nitrogen and argon contaminants in order to meet pipeline specifications.

[0005] Therefore, a need exists for systems and processes that enable generating steam with efficient carbon dioxide recovery.

BRIEF SUMMARY OF THE DISCLOSURE

[0006] In one embodiment, a method of steam assisted oil recovery integrated with carbon dioxide capture includes feeding water to a steam generator that produces injection steam and liquid blowdown separated from the injection steam at a first pressure. The method further includes introducing the injection steam into a formation for the steam assisted oil recovery, flashing the blowdown at a second pressure lower

than the first pressure to provide regenerator steam and condensate, and passing the condensate through a heat exchanger to preheat the water prior to the water entering the steam generator. A carbon dioxide recovery unit uses the regenerator steam in capturing carbon dioxide from flue gas exhaust of the steam generator.

[0007] According to one embodiment, a method of steam assisted oil recovery integrated with carbon dioxide capture includes feeding water to a steam generator that produces injection steam and liquid blowdown separated from the injection steam at a first pressure. In addition, the method includes introducing the injection steam into a formation for the steam assisted oil recovery, flashing the blowdown at a second pressure lower than the first pressure to provide regenerator steam and condensate, and supplying the regenerator steam to a carbon dioxide recovery unit for use in capturing carbon dioxide from flue gas exhaust of the steam generator. The blowdown without additional steam input provides all steam requirements for solvent regeneration in the carbon dioxide recovery unit.

[0008] For one embodiment, a method of steam assisted oil recovery integrated with carbon dioxide capture includes feeding water to a steam generator that produces injection steam and liquid blowdown separated from the injection steam at a first pressure. The method also includes introducing the injection steam into a formation for the steam assisted oil recovery, flashing the blowdown at a second pressure lower than the first pressure to provide regenerator steam and condensate, and supplying the regenerator steam to a carbon dioxide recovery unit for use in capturing carbon dioxide from flue gas exhaust of the steam generator. Passing combustion exhaust of a regenerator boiler for the carbon dioxide recovery unit through a heat exchanger preheats one of air and the water that are then supplied to the steam generator.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] A more complete understanding of the present invention and benefits thereof may be acquired by referring to the following description taken in conjunction with the accompanying drawings in which:

[0010] Figure 1 is a schematic of a production system for integrated steam assisted oil recovery and carbon dioxide capture, according to one embodiment of the invention.

[0011] Figure 2 is a schematic of an alternative system for integrated steam assisted oil recovery and carbon dioxide capture, according to one embodiment of the invention.

DETAILED DESCRIPTION

[0012] Turning now to the detailed description of the preferred arrangement or arrangements of the present invention, it should be understood that the inventive features and concepts may be manifested in other arrangements and that the scope of the invention is not limited to the embodiments described or illustrated. The scope of the invention is intended only to be limited by the scope of the claims that follow.

[0013] Methods and systems generate steam for injection into a formation in order to facilitate oil recovery and also capture carbon dioxide in a recovery unit that receives flue gas exhaust from such steam generation. The methods and systems integrate various process streams from and to the carbon dioxide recovery unit. Such integration provides resulting benefits associated with efficiency and/or carbon dioxide avoidance.

[0014] Figure 1 shows a system that includes a water feed 100 preheated in a first heat exchanger 102 with production fluids 104 recovered from a hydrocarbon bearing formation. The water 100 then enters a steam generator 106 such as a once-through steam generator (OTSG). The steam generator 106 produces injection steam 108 by a single-pass of the water 100 through boiler tubes heated by burners that combust air and fuel also supplied to the steam generator 106.

[0015] In operation, the injection steam 108, which may be saturated and at a pressure above 5000 kilopascals (kPa), passes through one or more injection wells and into the hydrocarbon bearing formation in order to reduce viscosity of the hydrocarbons. The steam condenses to create an oil/water mixture that migrates through the formation. The oil/water mixture gathers at one or more production wells, is brought to surface and forms at least part of the production fluids 104. Steam assisted gravity drainage (SAGD) provides an example of such an application where the systems described herein may be employed.

[0016] The combustion of the air and fuel in the steam generator 106 creates a flue gas exhaust 110. In some embodiments, the exhaust 110 passes through a second heat exchanger 112 to facilitate preheating of the water 100 prior to the water 100 entering the steam generator 106. A carbon dioxide recovery unit 114 receives the exhaust 110 for

separating a carbon dioxide output 116 from other flue gas constituents. The carbon dioxide output 116 from the carbon dioxide recovery unit 114 enables subsequent compressing and/or sequestering thereof to avoid emitting the carbon dioxide into the atmosphere.

[0017] For some embodiments, the steam generator 106 may operate at from 5000 kPa to 11,000 kPa based on pressure of the water 100 pumped into the steam generator 106. The steam generator 106 provides initial wet steam that may be about 70 percent to 80 percent quality steam before separating out the injection steam 108. Therefore, a liquid blowdown 118 also exits from the steam generator 106.

[0018] A separator 120 with flow control to reduce pressure of the blowdown 118 flashes part of the blowdown 118 to produce condensate 122 that may also be used to preheat the water 100 introduced into the steam generator 106 using a third heat exchanger 124. Flashing of the blowdown 118 in the separator 120 further produces regenerator steam 126 at lower pressure than the injection steam 108. For example, the separator 120 may produce the regenerator steam 126 at pressures, such as between 325 kPa and 425 kPa, desired for use in capturing carbon dioxide rather than higher pressures desired for the injection steam 108. The steam is desired to be at such lower pressure relative to output of the injection steam 108 by the steam generator 106 so that special metallurgy is not required in the carbon dioxide recovery unit 114 to contain pressures and so that desired temperatures based on solvent desorption energy and solvent degradation in the carbon dioxide recovery unit 114 can be achieved.

[0019] By way of example, the carbon dioxide recovery unit 114 may utilize a selective amine solution to strip the carbon dioxide from the other flue gas constituents by absorption of the carbon dioxide within the solution. The amine solution comes in direct contact with the flue gas exhaust 110 in an absorber of the carbon dioxide recovery unit 114. The other flue gas constituents pass through the absorber and may exit the carbon dioxide recovery unit 114 as treated exhaust via discharge that opens to the atmosphere.

[0020] Ethanolamine(s) and/or other suitable solvents may be used for the absorber solutions in some embodiments. Once the amine solution has been used to separate the carbon dioxide, the amine solution can be regenerated in a regenerator of the carbon dioxide recovery unit 114 by use of the regenerator steam 126. For some embodiments,

liberation of the carbon dioxide from the amine solution may occur with temperature increase and pressure reduction.

[0021] In some embodiments, the separator 120 may supply all steam requirements for the carbon dioxide recovery unit 114 without any additional steam being generated or otherwise input, such as by utilizing part of the injection steam 108 and reducing pressure thereof, to thus avoid creating additional flue gases and limit boiler capital costs. To facilitate not having to supplement the regenerator steam 126 from the separator 120, all of the blowdown 118 from the steam generator 106 may be utilized for the flashing to produce the regenerator steam 126 without splitting or diverting energy content of the blowdown 118 for other purposes before the flashing that forms the condensate stream 122 with energy content below that required to create the regenerator steam 126. Selection of the solvents used for the absorber solutions in the carbon dioxide recovery unit 114 may further assist in meeting all steam requirements for the carbon dioxide recovery unit 114 with only that from the separator 120.

[0022] For some embodiments, a regenerator boiler 128 may supplement supply of the regenerator steam 126 to the carbon dioxide recovery unit 114 even though the boiler 128 may be sized smaller than if the boiler 128 provided all steam requirements to the carbon dioxide recovery unit 114. Combustion products from burning of air and fuel to vaporize water in the boiler 128 may combine with the exhaust of the steam generator 106. This exhaust of boiler 128 thus passes through the second heat exchanger 112 to assist in preheating of the water 100 going into the steam generator 106.

[0023] Figure 2 illustrates an alternative system with like components as shown in Figure 1 identified by common reference numbers. This alternative system further functions in a similar manner as described already herein except that the exhaust 110 from the steam generator 106 and/or the regenerator boiler 128 passes through an air preheater 212 for raising temperature of the air supplied to the steam generator 106. The exhaust 110 then exits the air preheater 212 and is treated in the carbon dioxide recovery unit 114.

[0024] In order to quantify benefits of the systems according to embodiments of the invention, modeling was used to compare various alternative approaches. Design basis for the modeling included the following parameters: steam production from 90,000

barrels of water per day; steam-to-oil ratio of 3:1; 75 percent quality steam at 309° C; and a 30 weight percent monoethanolamine used for carbon dioxide capture. A base case Comparative System was evaluated that recovered heat from flashed blowdown of the steam generator being heat exchanged with water input into the steam generator since a standalone carbon dioxide capture unit was employed, for comparison to an otherwise analogous Example System as shown in Figure 1.

[0025] The following table depicts unexpected results due to the Example System being more efficient compared to the Comparative System while providing higher carbon dioxide emission avoidance and smaller carbon dioxide footprint as desired. The efficiency results in lower operating costs. Reduced equipment sizing also contributes to lower capital costs.

	Comparative System	Example System
Efficiency loss due to carbon dioxide capture	16.4%	8.4%
Carbon dioxide emission avoidance	65.2%	66.5%
Operating cost per relative amount	1.00	0.76
Capital cost per relative amount	1.00	0.95

[0026] In addition, the systems described herein were compared to modeling results for oxy-fuel combustion systems as an alternative approach for capturing of the carbon dioxide. Fuel usage for the systems described herein overlapped with that of the oxy-fuel combustion systems. Even though operating costs from fuel usage may not provide a decisive benefit, the oxy-fuel combustion systems only provided a carbon dioxide emission avoidance of less than 34% whereas the Example System as shown above was 66.5%. Electrical use required by an air separation unit for the oxy-fuel combustion systems contributes to this limited carbon dioxide emission avoidance when using the oxy-fuel combustion systems.

[0027] In closing, it should be noted that the discussion of any reference is not an admission that it is prior art to the present invention, especially any reference that may have a publication date after the priority date of this application. At the same time, each and every claim below is hereby incorporated into this detailed description or specification as additional embodiments of the present invention.

[0028] Although the systems and processes described herein have been described in detail, it should be understood that various changes, substitutions, and alterations can be made without departing from the spirit and scope of the invention as defined by the following claims. Those skilled in the art may be able to study the preferred embodiments and identify other ways to practice the invention that are not exactly as described herein. It is the intent of the inventors that variations and equivalents of the invention are within the scope of the claims while the description, abstract and drawings are not to be used to limit the scope of the invention. The invention is specifically intended to be as broad as the claims below and their equivalents.

CLAIMS

1. A method of steam assisted oil recovery integrated with carbon dioxide capture, comprising:

feeding water to a steam generator that produces injection steam and liquid blowdown separated from the injection steam at a first pressure;

introducing the injection steam into a formation for the steam assisted oil recovery;

flashing the blowdown at a second pressure lower than the first pressure to provide regenerator steam and condensate;

passing the condensate through a heat exchanger to preheat the water prior to the water entering the steam generator; and

supplying the regenerator steam to a carbon dioxide recovery unit for use in capturing carbon dioxide from flue gas exhaust of the steam generator.

2. A method of steam assisted oil recovery integrated with carbon dioxide capture, comprising:

feeding water to a steam generator that produces injection steam and liquid blowdown separated from the injection steam at a first pressure;

introducing the injection steam into a formation for the steam assisted oil recovery;

flashing the blowdown at a second pressure lower than the first pressure to provide regenerator steam and condensate; and

supplying the regenerator steam to a carbon dioxide recovery unit for use in capturing carbon dioxide from flue gas exhaust of the steam generator, wherein the blowdown without additional steam input provides all steam requirements for solvent regeneration in the carbon dioxide recovery unit.

3. A method of steam assisted oil recovery integrated with carbon dioxide capture, comprising:

feeding water to a steam generator that produces injection steam and liquid blowdown separated from the injection steam at a first pressure;

introducing the injection steam into a formation for the steam assisted oil recovery;

flashing the blowdown at a second pressure lower than the first pressure to provide regenerator steam and condensate;

supplying the regenerator steam to a carbon dioxide recovery unit for use in capturing carbon dioxide from flue gas exhaust of the steam generator; and

passing combustion exhaust of a regenerator boiler for the carbon dioxide recovery unit through a heat exchanger to preheat one of air and the water that are then supplied to the steam generator.

4. The method according to one of claims 1 through 3, further comprising heat exchanging combustion exhaust of a regenerator boiler for the carbon dioxide recovery unit with air supplied to the steam generator.

5. The method according to one of claims 1 through 4, further comprising heat exchanging combustion exhaust of a regenerator boiler for the carbon dioxide recovery unit with the water prior to the water entering the steam generator.

6. The method according to one of claims 1 through 5, wherein the blowdown without additional steam input provides all steam requirements for solvent regeneration in the carbon dioxide recovery unit.

7. The method according to one of claims 1 through 6, wherein all the blowdown is flashed to produce the regenerator steam without diverting energy content of the blowdown.

8. The method according to one of claims 1 through 7, further comprising recovering products from the formation and heat exchanging at least some of the products with the water prior to the water entering the steam generator.

9. The method according to one of claims 1 through 8, wherein the first pressure is between 5000 kilopascals (kPa) and 11,000 kPa and the second pressure is between 325 kPa and 425 kPa.

10. The method according to one of claims 1 through 9, wherein the carbon dioxide recovery unit is based on amine solution absorption of carbon dioxide.
11. The method according to one of claims 1 through 10, wherein the regenerator steam is used to liberate carbon dioxide from an amine solution in the carbon dioxide recovery unit.
12. The method according to one of claims 1 through 11, wherein the steam generator is a once-through steam generator.
13. The method according to one of claims 1 through 12, wherein the injection steam is all saturated steam produced by the steam generator at the first pressure.
14. The method according to one of claims 1 through 13, further comprising compressing and sequestering a carbon dioxide output from the carbon dioxide recovery unit.
15. The method according to one of claims 1 through 14, wherein the combustion exhaust of a regenerator boiler for the carbon dioxide recovery unit is combined with the flue gas exhaust of the steam generator before being heat exchanged with one of air and the water, which is thereby preheated and supplied to the steam generator.
16. The method according to one of claims 1 through 15, wherein all the injection steam is injected into the formation and is all saturated steam produced by the steam generator at the first pressure.
17. The method according to one of claims 1 through 16, wherein the combustion exhaust of the regenerator boiler preheats the air supplied to the steam generator.
18. The method according to one of claims 1 through 17, wherein the combustion exhaust of the regenerator boiler preheats the water supplied to the steam generator.
19. The method according to one of claims 1 through 18, wherein the combustion exhaust of the regenerator boiler is combined with the flue gas exhaust of the steam generator before being passed through the heat exchanger.

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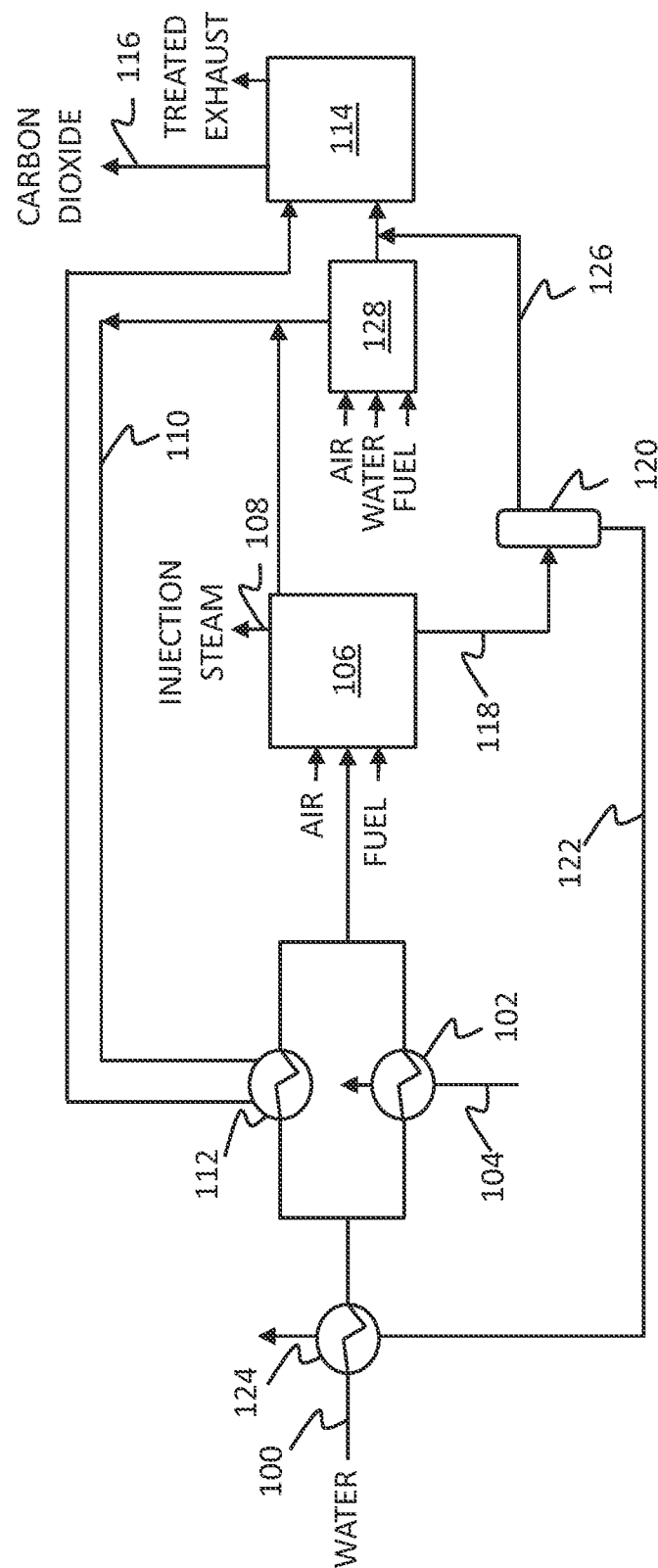


FIG. 1

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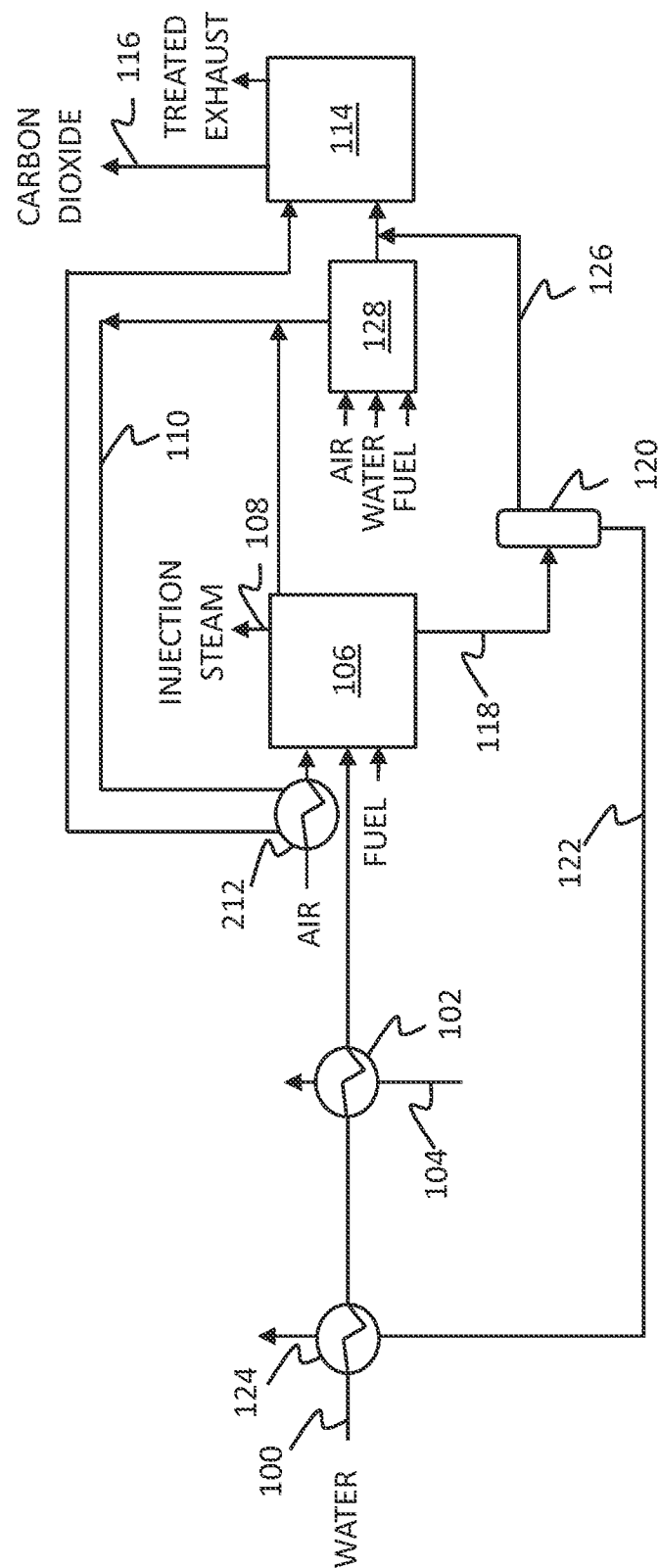


FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 14/41948

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - E21B 43/24 (2014.01)

CPC - E21B 43/24; Y02C 10/00

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)

IPC(8) - E21B 43/24 (2014.01)

CPC - E21B 43/24; Y02C 10/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - E21B 41/0064

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Patbase; Google Patents; Google Scholar; Google Web; Espacenet; Search Terms: air, assist*, blowdown*, captur*, carbon dioxide*, condensate*, CO2, exchang*, exhaust*, flash*, flue*, generat*, greenhouse, gas*, heat exchang*, preheat*, reboiler*, recover*, regen*, SAGD, sequest*, steam, water

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2010/0206565 A1 (Embry et al.) 19 August 2010 (19.08.2010), entire document, especially Fig. 1, para [0003], [0018], [0020]-[0022]	2 --- 1, 3, 4/(1-3)
Y	US 2010/0147516 A1 (Betzer-Zilevitch) 17 June 2010 (17.06.2010), entire document, especially para [0114]	1, 4/(1)
Y	US 2012/0318141 A1 (Tsujiuchi et al.) 20 December 2012 (20.12.2012), para [0091]	3, 4/(1-3)
A	US 2013/0062065 A1 (Tsujiuchi et al.) 14 March 2013 (14.03.2013) para [0043]-[0046]	1-3, 4/(1-3)
A	US 2010/0282644 A1 (O'Connor et al.) 11 November 2010 (11.11.2010), Figs. 3-4, para [0063]-[0065]	1-3, 4/(1-3)
A	US 2012/0222426 A1 (Macadam) 06 September 2012 (06.09.2012), Fig. 1, para [0025]	1-3, 4/(1-3)

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

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"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

08 September 2014 (08.09.2014)

Date of mailing of the international search report

03 OCT 2014

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents

P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-3201

Authorized officer:

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PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No. .

PCT/US 14/41948

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 5-19
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.