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

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
12 December 2024 (12.12.2024)

WIPO | PCT

(10) **International Publication Number**
WO 2024/251411 A1

(51) **International Patent Classification:**
B01D 53/04 (2006.01) ***H01F 27/00*** (2006.01)

(21) **International Application Number:** PCT/EP2024/058903

(22) **International Filing Date:** 02 April 2024 (02.04.2024)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**
63/471,434 06 June 2023 (06.06.2023) US

(71) **Applicant: HITACHI ENERGY LTD** [CH/CH]; Brown-Boveri-Strasse 5, 8050 Zürich (CH).

(72) **Inventors: CHEIM, Luiz**; 1105 Barley Stone Way, Raleigh, North Carolina 27603 (US). **SBRAVATI, Alan**; 5053 Kota Street, Raleigh, North Carolina 27610 (US).

(74) **Agent: EPPING HERMANN FISCHER PATENTANWALTSGESELLSCHAFT MBH**; Schlossschmidstr. 5, 80639 Munich (DE).

(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))*
— *of inventorship (Rule 4.17(iv))*

Published:
— *with international search report (Art. 21(3))*
— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

(54) **Title:** SYSTEM AND METHOD FOR UTILIZING TRANSFORMER WASTED ENERGY WITH MODULAR CO2 CAPTURE SYSTEMS

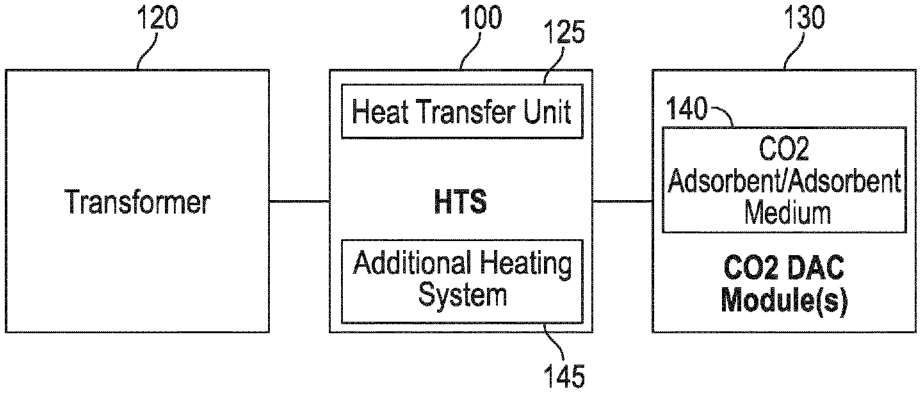


FIG. 1

(57) **Abstract:** A system of using thermal energy in the form of wasted heat of a transformer to minimize required energy for CO2 Direct Air Capture (DAC) operation comprising a heat transfer unit configured to be coupled to a transformer and receiv wasted heat in the form of hot insulating liquid, and configured to be coupled to one or more CO2 DAC modules including CO2 adsorbent or absorbent medium to transfer wasted heat from the hot insulating liquid in the heat transfer unit to the one or more CO2 DAC modules where the transferred heat is used to heat the CO2 adsorbent or absorbent medium to minimize requid energy for CO2 DAC operation.

WO 2024/251411 A1

SYSTEM AND METHOD FOR UTILIZING TRANSFORMER WASTED ENERGY WITH MODULAR CO2 CAPTURE SYSTEMS

TECHNICAL FIELD

[1] The embodiments described herein are generally directed to carbon dioxide (“CO2”) capturing heating systems and method.

BACKGROUND

[2] Examples of CO2 Direct Air Capture systems (DAC) for capturing carbon dioxide directly from air include fans which push air through a filter system that collects CO2. When the filter is saturated, CO2 is separated at high temperatures, which can then be used for variety of applications, such as growing vegetables, carbonating beverages, etc. CO2 DAC systems require a significant amount of energy to elevate capture unit temperature from ambient temperature, which may be around 20-40 degrees C to CO2 desorption temperature, which may be about 100-120 degrees C. This cyclic temperature variation is a very energy intensive process, often being a limitation for the economic viability of the application of the DAC technology.

SUMMARY

[3] An aspect of the disclosure involves a system of using thermal energy in the form of wasted heat of a transformer to minimize required energy for CO2 Direct Air Capture (DAC) operation comprising a heat transfer unit configured to be coupled to a transformer and receive wasted heat in the form of hot insulating liquid, and configured to be coupled to one or more CO2 DAC modules including CO2 absorbent medium to transfer wasted heat from the hot insulating liquid in the heat transfer unit to the one or more CO2 DAC modules where the transferred heat is used to heat the CO2 absorbent medium to minimize required energy for CO2 DAC operation.

[4] One or more implementations of the above aspect of the disclosure described immediately above comprises one or more of the following: an additional heating system configured to ensure that a second heat transfer liquid, which is independent of the hot insulating liquid from the transformer, is continuously at a required temperature for desorption of CO2 in the one or more CO2 DAC modules; the heat transfer unit is a heat exchanger; the additional heating system is a hot insulating liquid bath that the heat exchanger is disposed within, and the heat exchanger is configured

to transfer heat from the hot insulating liquid to the second heat transfer liquid, and the hot insulating liquid bath is configured to ensure that the second heat transfer liquid is continuously at the required temperature for desorption of CO2 in the one or more CO2 DAC modules.

[5] Another aspect of the disclosure involves a method of using thermal energy in the form of wasted heat of a transformer to minimize required energy for CO2 Direct Air Capture (DAC) operation comprising receiving wasted heat in the form of hot insulating liquid from a transformer; transferring wasted heat from the hot insulating liquid in the heat transfer unit to one or more CO2 DAC modules where the transferred heat is used to heat CO2 absorbent medium in the one or more CO2 DAC modules to minimize required energy for CO2 DAC operation.

[6] One or more implementations of the above aspect of the disclosure described immediately above comprises one or more of the following: heating a second heat transfer liquid, which is independent of the hot insulating liquid from the transformer, with the hot insulating liquid from the transformer; and/or additionally heating the second heat transfer liquid to a required temperature for desorption of CO2 in the one or more CO2 DAC modules.

BRIEF DESCRIPTION OF THE DRAWINGS

[7] The details of the present disclosure, both as to its structure and operation, may be gleaned in part by study of the accompanying drawings, in which like reference numerals refer to like parts, and in which:

[8] FIG. 1 is a simplified schematic of an embodiment of a system of using thermal energy in the form of wasted heat of a transformer to minimize required energy for CO2 Direct Air Capture (DAC) operation.

[9] FIG. 2 is a schematic of an embodiment of a CO2 DAC module of FIG. 1;

[10] FIG. 3 is a more detailed schematic of the system of FIG. 1;

[11] FIG. 4 is a flow chart of an exemplary method of using thermal energy in the form of wasted heat of a transformer to minimize required energy for CO2 Direct Air Capture (DAC) operation.

DETAILED DESCRIPTION

[12] With reference generally to FIGS. 1-3, an embodiment of a system 100 of using thermal energy in the form of wasted heat of a transformer 120 to minimize required energy for CO2 Direct Air Capture (DAC) operation or transformer wasted energy heat transfer system ("HTS") will be described. The system 100 includes a heat transfer unit 125 configured to be coupled to the transformer 120 and receive wasted heat in the form of hot insulating liquid (e.g., mineral oil, natural ester, synthetic ester, silicone fluid, LFH (less flammable hydrocarbons), or bio-based hydrocarbons), and configured to be coupled to one or more CO2 DAC modules 130 including CO2 adsorbent or absorbent medium 140 to transfer wasted heat from the hot insulating liquid in the heat transfer unit 125 to the one or more CO2 DAC modules 130 where the transferred heat is used to heat the CO2 adsorbent or absorbent medium 140 for reducing the energy required to raise the material temperature to a desired setpoint temperature (e.g., 100-120 degrees C) for desorption of the CO2 from the CO2 adsorbent or absorbent medium 140. Although 100-120 degrees C is provided as an example of the desired setpoint temperature, the desired setpoint temperature may fluctuate with sorbent efficiency. An additional heating system 145 ensures that there is sufficient transferred heat to the CO2 adsorbent or absorbent medium 140 to raise the material temperature to the desired setpoint temperature.

[13] As illustrated in FIG. 2, the one or more CO2 DAC modules 130 may be industrial modules for CO2 removal that are self-contained and have the necessary equipment to perform the CO2 removal and storage. The CO2 DAC module(s) 130 include one or more fans 150 mounted to housing 160 to force air circulation through the CO2 adsorbent or absorbent medium 140 to separate CO2 from the ambient air. A CO2 DAC module heat exchanger 170 receives and uses the hot insulating liquid from the system 100 to heat up the CO2 adsorbent or absorbent medium 140 to the desired setpoint temperature for desorption of the CO2 from the CO2 adsorbent or absorbent medium 140. Flushed CO2 may be drawn out of the CO2 DAC module(s) 130 via a vacuum / filtration system 180, exit the CO2 DACs at exit 190, pass through one or more conduits 200 and delivered via a compressor 210 to/for a destination/application 220 (e.g., connecting to CO2 pipeline, underground injection, bottled transportation, local storage in tanks). The DAC modules hereby described is one example of DAC systems. It is not intended to limit the application of the present disclosure.

[14] As illustrated in FIG. 3, the additional heating system 145 of the system 100 is a hot insulating liquid bath 230 and the heat transfer unit 125 is a hot insulating liquid bath heat exchanger 240 disposed in the hot insulating liquid bath 230. The system 100 further includes conduits 250 that couple ports 260, 270 of a hot insulating liquid manifold 280 to the heat exchanger 240, and conduits 290 that couple the hot insulating liquid bath 230 to the CO2 DAC module(s) 130 (e.g., at hot insulating liquid inlet 300, hot insulating liquid outlet 310). The hot insulating liquid manifold 280 may be part of a transformer cooling system 315. Wasted energy hot insulating liquid (e.g., at 80 – 90 degrees C) from the hot insulating liquid manifold 270 is transferred to the heat exchanger 240 to heat a second heat transfer liquid or an alternative heat transfer mechanism ("AHTM"), which is separate/independent from the hot insulating liquid from the hot insulating liquid manifold 270, in the hot insulating liquid bath 230 and returned to the hot insulating liquid manifold 280. The hot insulating liquid bath 230 heats the independent second heat transfer liquid or alternative heat transfer mechanism therein (e.g., to 100 – 120 degrees C), which is transferred from the hot insulating liquid bath 230 to the heat exchanger 170 of the CO2 DAC module(s) 130 via the conduits 290. The heat exchanger 170 transfers heat from the circulated second heat transfer liquid or alternative heat transfer mechanism from the hot insulating liquid bath 230 to the CO2 adsorbent or absorbent medium 140 to the desired setpoint temperature (e.g., about 100-120 degrees C) for CO2 desorption. Thus, the additional heating system 145 ensures that a second heat transfer liquid or alternative heat transfer mechanism, which is independent of the hot insulating liquid from the transformer 120, is continuously at a required temperature for desorption of CO2 in the one or more CO2 DACs.

[15] With reference to FIG. 4, a method 350 of using the transformer wasted energy heat transfer system 100 will now be described. In block 360, the system 100 receives (e.g., via the heat exchanger 240 disposed in the hot insulating liquid bath 230) wasted heat in the form of hot insulating liquid from the transformer 120 (e.g., via transformer cooling system 315). In optional block 370, if needed, the system 100 heats a second heat transfer liquid or alternative heat transfer mechanism (e.g., via the hot insulating liquid bath 230), which is independent of the hot insulating liquid from the transformer 120, with the hot insulating liquid from the transformer 120. In optional block 380, if needed, the system 100 additionally heats the second heat transfer liquid or alternative heat transfer mechanism to a required temperature for desorption of CO2 in the one or more CO2 DAC modules 130. In block 390, the system 100 transfers heat (e.g., via the heat transfer unit 125

and the second heat transfer liquid in the heat transfer liquid bath 230) to the heat exchanger 170 of the CO2 DAC module(s) 130 where the transferred heat is used to heat the CO2 adsorbent or absorbent medium 140 to minimize required energy for CO2 Direct Air Capture (DAC) operation. Alternative heat transfer mechanism(s)/technologies may also be used instead of the heat exchanger 170, still utilizing the wasted heat from the insulating liquid of a transformer.

[16] A main advantage of the system 100 and method 350 include the minimization of energy required to raise the CO2 DAC module temperature (e.g., to 100-120 degrees C, typically from ambient around 20 degrees C, a delta of at least about 80 degrees C) by utilizing the thermal energy that needs to be removed from transformer 120 for preventing its overheating as an input to raise the CO2 DAC module temperature. Assuming wasted hot insulating liquid from the transformer cooling system 315 is at about 80-90 degrees C, such delta in temperature (and consequently in required energy) would reduce drastically, thus making the entire system more efficient and utilizing transformer wasted energy to benefit the environment and companies to accrue carbon credits.

[1] The above description of the disclosed embodiments is provided to enable a person skilled in the art to make or use the invention. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the general principles described herein can be applied to other embodiments without departing from the spirit or scope of the invention. Thus, it is to be understood that the description and drawings presented herein represent a presently preferred embodiment of the invention and are therefore representative of the subject matter which is broadly contemplated by the present invention. It is further understood that the scope of the present invention fully encompasses other embodiments that may become obvious to those skilled in the art and that the scope of the present invention is accordingly not limited.

[2] Combinations, described herein, such as “at least one of A, B, or C,” “one or more of A, B, or C,” “at least one of A, B, and C,” “one or more of A, B, and C,” and “A, B, C, or any combination thereof” include any combination of A, B, and/or C, and may include multiples of A, multiples of B, or multiples of C. Specifically, combinations such as “at least one of A, B, or C,” “one or more of A, B, or C,” “at least one of A, B, and C,” “one or more of A, B, and C,” and “A, B, C, or any combination thereof” may be A only, B only, C only, A and B, A and C, B and C, or A and B and C, and any such combination may contain one or more members of its constituents A, B, and/or C. For example, a combination of A and B may comprise one A and multiple B’s, multiple A’s and one B, or multiple A’s and multiple B’s.

CLAIMS

What is claimed is:

1. A system (100) of using thermal energy in the form of wasted heat of a transformer to minimize required energy for CO2 Direct Air Capture (DAC) operation, comprising:

a heat transfer unit (125) configured to be coupled to a transformer (120) and receive wasted heat in the form of hot insulating liquid, and configured to be coupled to one or more CO2 DAC modules (130) including CO2 adsorbent medium (140) to transfer wasted heat from the hot insulating liquid in the heat transfer unit (125) to the one or more CO2 DAC modules (130) where the transferred heat is used to heat the CO2 adsorbent medium (140) to minimize required energy for CO2 DAC operation.

2. The transformer wasted energy heat transfer system (100) of claim 1, further comprising

an additional heating system (145) configured to ensure that a second heat transfer liquid or alternative heat transfer mechanism, which is independent of the hot insulating liquid from the transformer (120), is continuously at a required temperature for desorption of CO2 in the one or more CO2 DAC modules (130).

3. The transformer wasted energy heat transfer system (100) of claim 2, wherein

the heat transfer unit (125) is a heat exchanger (240).

4. The transformer wasted energy heat transfer system (100) of claim 3, wherein

the additional heating system (145) is a heat transfer liquid bath (230) that the heat exchanger (240) is disposed within, and the heat exchanger (240) is configured to transfer heat from the hot insulating liquid to the second heat transfer liquid, and the heat transfer liquid bath (230) is configured to ensure that the second heat transfer liquid is continuously at the required temperature for desorption of CO2 in the one or more CO2 DAC modules.

5. A method of using thermal energy in the form of wasted heat of a transformer to minimize required energy for CO2 Direct Air Capture (DAC) operation, comprising:

receiving wasted heat in the form of hot insulating liquid from a transformer (120);

transferring wasted heat from the hot insulating liquid in the heat transfer unit (125) to one or more CO2 DAC modules (130) where the transferred heat is used to heat CO2 adsorbent medium (140) in the one or more CO2 DAC modules (130) to minimize required energy for CO2 DAC operation.

6. The method of claim 5, further comprising

heating a second heat transfer liquid or alternative heat transfer mechanism, which is independent of the hot insulating liquid from the transformer (120), with the hot insulating liquid from the transformer (120);

7. The method of claim 6, further comprising

additionally heating the second heat transfer liquid or alternative heat transfer mechanism to a required temperature for desorption of CO2 in the one or more CO2 DAC modules (130).

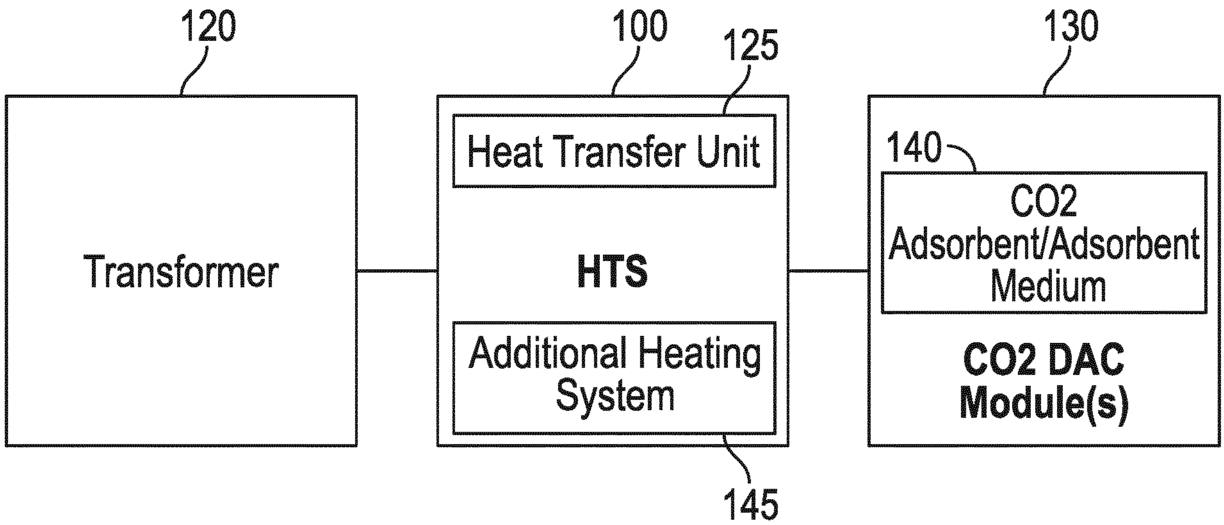

120
100
125
130
Transformer
Heat Transfer Unit
HTS
Additional Heating System
140
CO2 Adsorbent/Adsorbent Medium
CO2 DAC Module(s)
145

FIG. 1

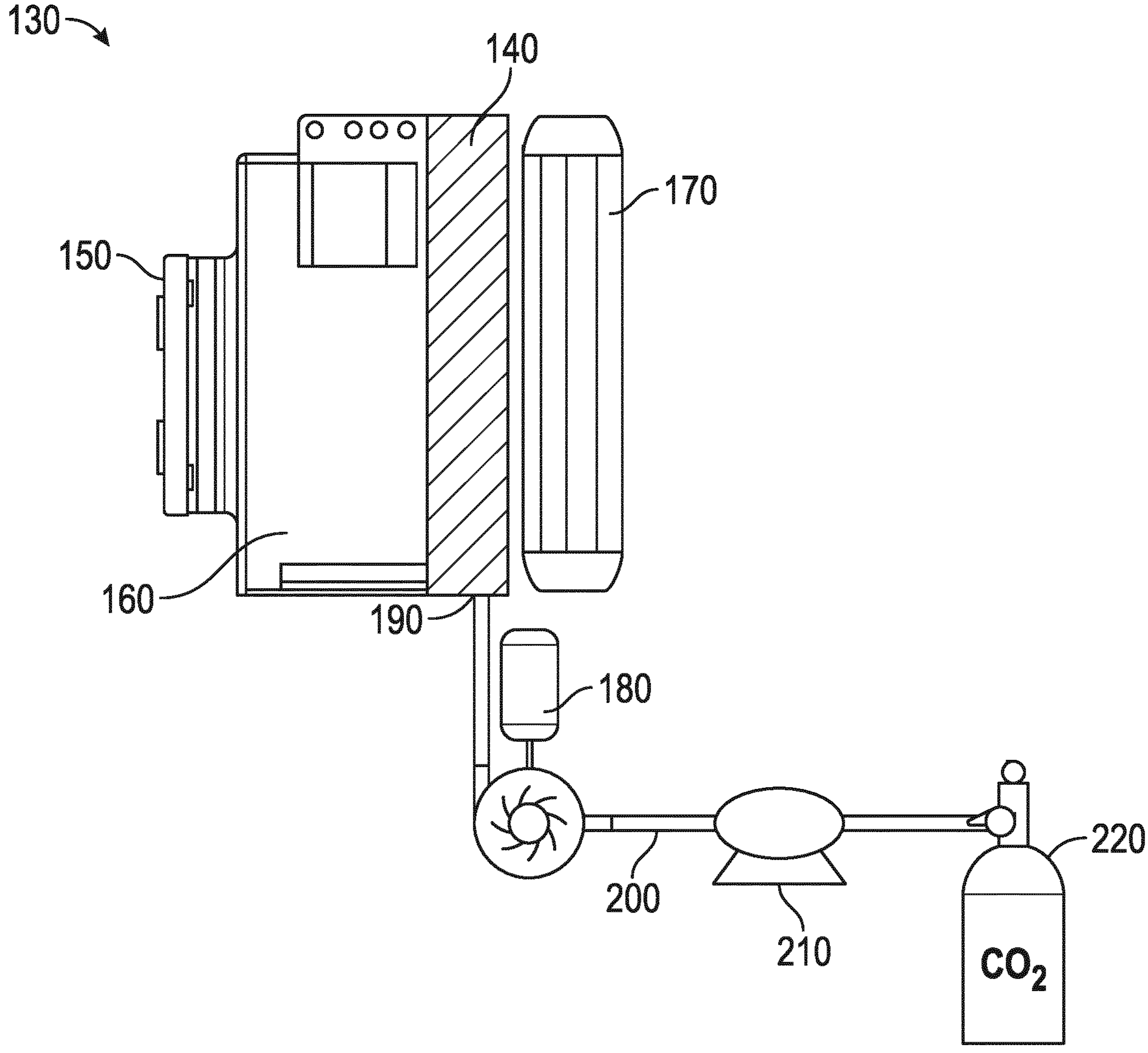
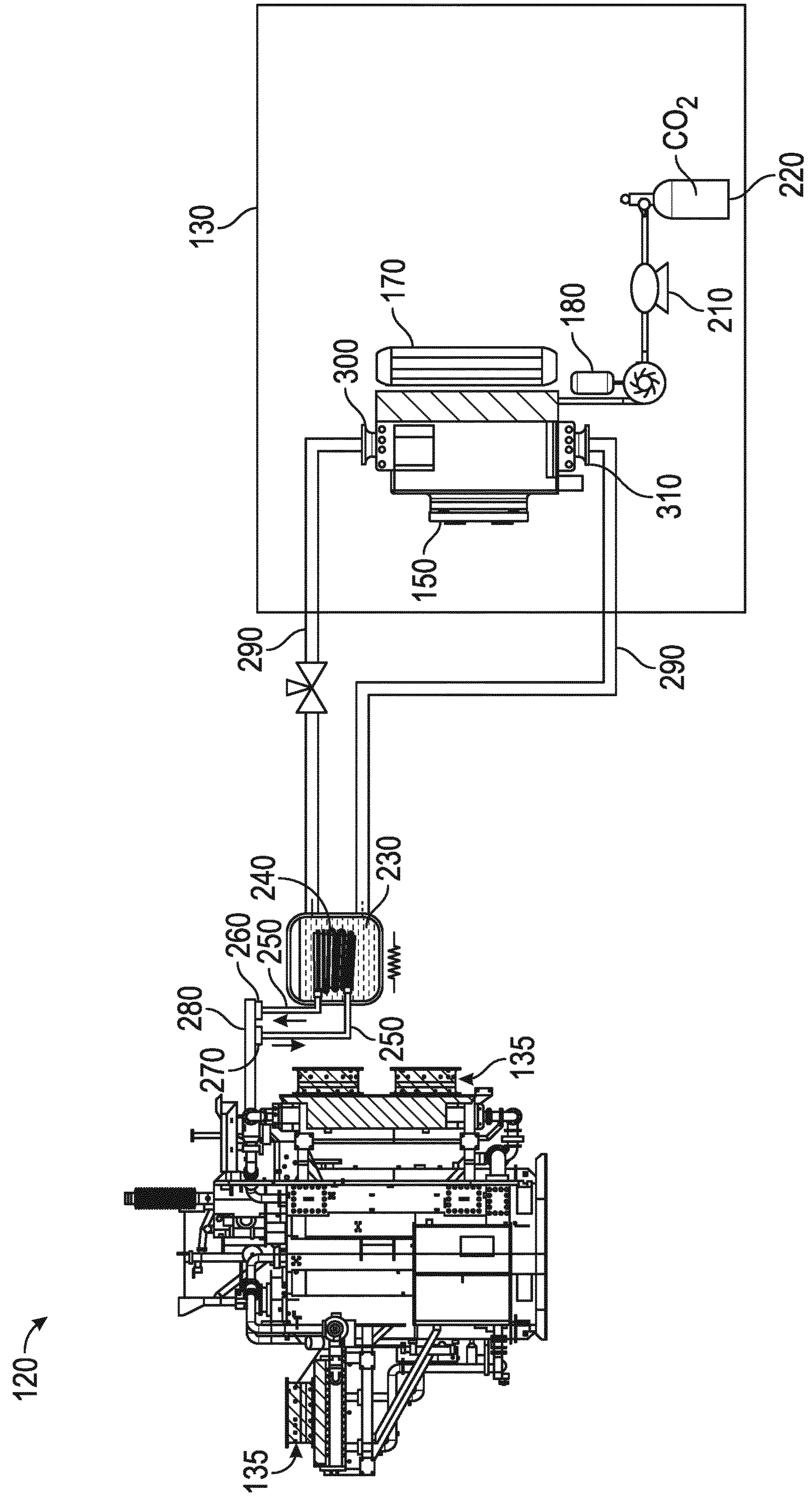


FIG. 2



130
170
180
300
310
150
CO_2
220
210
290
290
240
230
260
250
250
280
270
135
135
120

FIG. 3

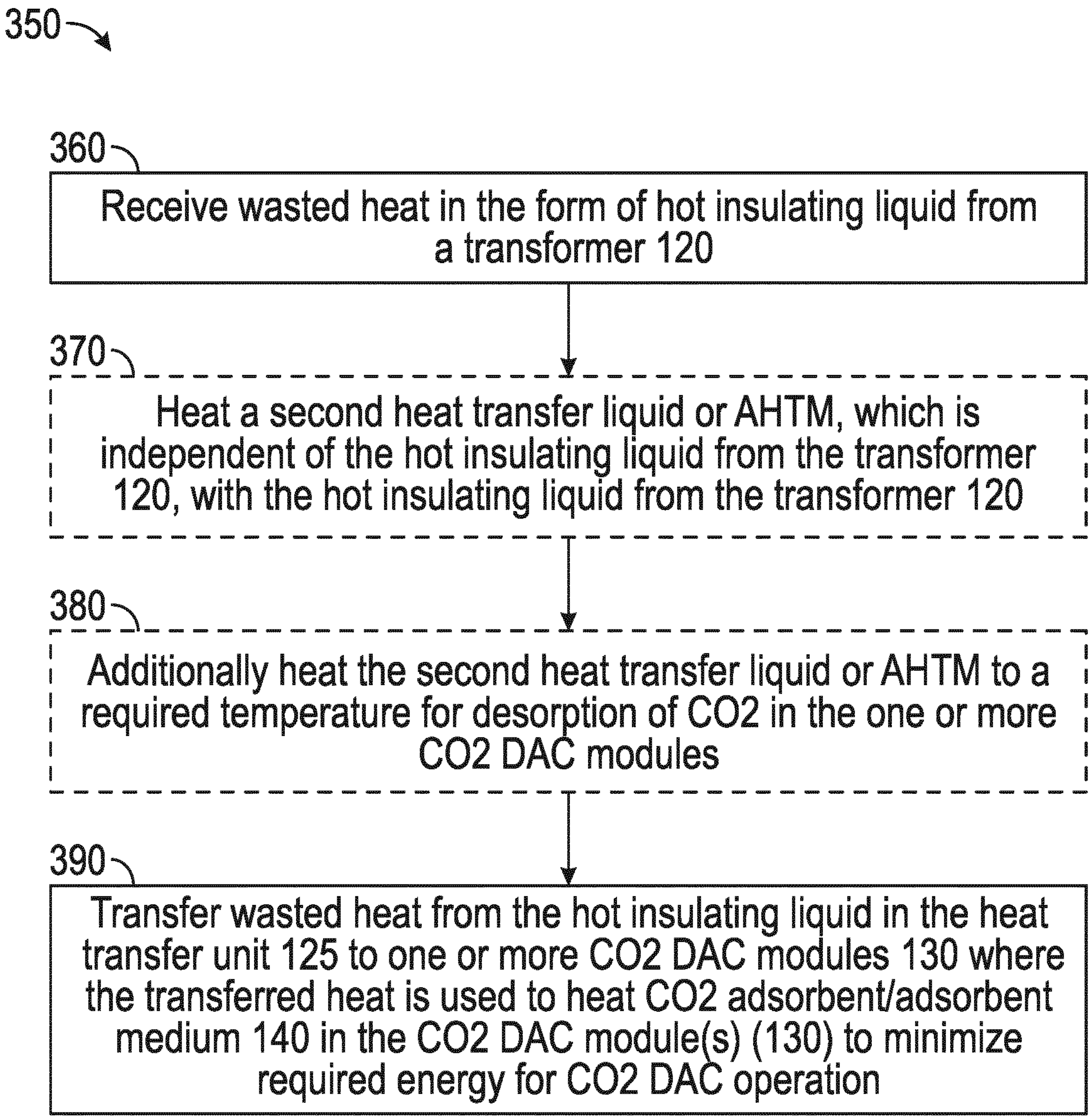

350
360
Receive wasted heat in the form of hot insulating liquid from a transformer 120
370
Heat a second heat transfer liquid or AHTM, which is independent of the hot insulating liquid from the transformer 120, with the hot insulating liquid from the transformer 120
380
Additionally heat the second heat transfer liquid or AHTM to a required temperature for desorption of CO2 in the one or more CO2 DAC modules
390
Transfer wasted heat from the hot insulating liquid in the heat transfer unit 125 to one or more CO2 DAC modules 130 where the transferred heat is used to heat CO2 adsorbent/adsorbent medium 140 in the CO2 DAC module(s) (130) to minimize required energy for CO2 DAC operation

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/058903

A. CLASSIFICATION OF SUBJECT MATTER
INV. B01D53/04 H01F27/00
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 H01F

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 2021/300765 A1 (GILROYSMITH BRYAN CHRISTOPHER [US] ET AL) 30 September 2021 (2021-09-30) paragraphs [0088], [0089], [0091] - [0095], [0099], [0102], [0114] - [0119]; figures 1-5 -----	1-3,5-7
X	WO 2021/258219 A1 (SOCPRA SCIENCES ET GENIE SEC [CA]) 30 December 2021 (2021-12-30) paragraphs [0004] - [0006], [0086] - [0113], [0136] - [0139] -----	1-7
A	WO 2023/066924 A1 (SHELL INT RESEARCH [NL]; SHELL USA INC [US]) 27 April 2023 (2023-04-27) page 6, line 26 - page 14, line 9; claims 1-11; figures 1-4 -----	1-7
	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* 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	Date of mailing of the international search report
7 July 2024	31/07/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Ruiz Martinez, Maria

3

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/058903

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 2 665 544 A1 (SAUDI ARABIAN OIL CO [SA]) 27 November 2013 (2013-11-27) paragraphs [0001], [0009] - [0020], [0066] - [0069]; figures 2-5 -----	1-7

3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2024/058903

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2021300765 A1	30-09-2021	CA 3176442 A1	07-10-2021
		EP 4111038 A1	04-01-2023
		US 2021300765 A1	30-09-2021
		US 2023278876 A1	07-09-2023
		WO 2021202499 A1	07-10-2021
WO 2021258219 A1	30-12-2021	CA 3186480 A1	30-12-2021
		CN 115803097 A	14-03-2023
		EP 4171783 A1	03-05-2023
		US 2023241546 A1	03-08-2023
		WO 2021258219 A1	30-12-2021
WO 2023066924 A1	27-04-2023	AU 2022372442 A1	11-04-2024
		CA 3234472 A1	27-04-2023
		CN 118139685 A	04-06-2024
		WO 2023066924 A1	27-04-2023
EP 2665544 A1	27-11-2013	CN 103492046 A	01-01-2014
		EP 2665544 A1	27-11-2013
		ES 2616028 T3	09-06-2017
		JP 5760097 B2	05-08-2015
		JP 2014509360 A	17-04-2014
		KR 20130119973 A	01-11-2013
		US 2013298532 A1	14-11-2013
		WO 2012100149 A1	26-07-2012