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(71) **Demandeur/Applicant:**
CONOCOPHILLIPS COMPANY, US

(72) **Inventeurs/Inventors:**
MACADAM, SCOTT, CA;
SEABA, JAMES P., CA;
LARKIN, DAVID WILLIAM, US

(74) **Agent:** OYEN WIGGS GREEN & MUTALA LLP

(54) **Titre : GENERATION DE VAPEUR A L'AIDE DU RECYCLAGE DE DIOXYDE DE CARBONE**
(54) **Title: STEAM GENERATION WITH CARBON DIOXIDE RECYCLE**

(57) **Abrégé/Abstract:**
Systems and methods relate to recovering hydrocarbons by injecting into a reservoir steam along with carbon dioxide recovered from flue gases produced while generating the steam and from separation of produced fluids. Due to benefits from the carbon dioxide injection, carbon dioxide capture rates from the flue gases selected below fifty percent in such combined recovery of the carbon dioxide enables lower fuel consumption even given that additional fuel is needed for the carbon dioxide capture versus steam only operations. As the capture rates from the flue gases increase above fifty percent like when employed for sequestration purposes, such approaches use more fuel than the steam only operations and may not be cost efficient. A carbon dioxide recovery unit coupled to an air-fired boiler or an auxiliary oxy-fired boiler may supply the carbon dioxide recovered from the flue gases.

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(71) Applicant: **CONOCOPHILLIPS COMPANY** [US/US]; Legal Dept. - Technology and Intellectual Property - Attn: Docketing, 600 N. Dairy Ashford, Houston, Texas 77079 (US).

(72) Inventors: **MACADAM, Scott**; 112 Whispering Water Hollow, Calgary, Alberta T3Z3T3 (CA). **SEABA, James P.**; 1604 - 1108 6th Ave. S.W., Calgary, Alberta T2P5K1 (CA). **LARKIN, David William**; 1435 E. 34th St., Tulsa, Oklahoma 74105 (US).

(74) Agent: **BERGER, Michael D.**; Conocophillips Company, Legal Dept. - Technology & Intellectual Property, 600 N. Dairy Ashford, Houston, Texas 77079 (US).

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(54) Title: STEAM GENERATION WITH CARBON DIOXIDE RECYCLE

(57) Abstract: Systems and methods relate to recovering hydrocarbons by injecting into a reservoir steam along with carbon dioxide recovered from flue gases produced while generating the steam and from separation of produced fluids. Due to benefits from the carbon dioxide injection, carbon dioxide capture rates from the flue gases selected below fifty percent in such combined recovery of the carbon dioxide enables lower fuel consumption even given that additional fuel is needed for the carbon dioxide capture versus steam only operations. As the capture rates from the flue gases increase above fifty percent like when employed for sequestration purposes, such approaches use more fuel than the steam only operations and may not be cost efficient. A carbon dioxide recovery unit coupled to an air-fired boiler or an auxiliary oxy-fired boiler may supply the carbon dioxide recovered from the flue gases.

STEAM GENERATION WITH CARBON DIOXIDE RECYCLE

FIELD OF THE INVENTION

[0001] Embodiments of the invention relate to methods and systems of producing a fluid of steam and carbon dioxide for injection into a reservoir to facilitate oil recovery.

BACKGROUND OF THE INVENTION

[0002] Enhanced oil recovery processes employ thermal methods to improve recovery of heavy oils from subsurface reservoirs. For example, injection of steam into heavy oil bearing formations heats the oil in the reservoir, which reduces the viscosity of the oil and allows the oil to flow to a collection well. A mixture of the oil and produced water that flows to the collection well is recovered to the surface where the oil is separated from the water.

[0003] Different approaches exist for generating the steam. Prior once through steam generators (OTSGs) produce a wet steam by a single pass of water through a boiler isolated from fluid communication with combustion used to heat the boiler. An alternative approach utilizes a direct steam generator (DSG) to produce steam by contacting water with products from oxy-fuel combustion.

[0004] Effluent from the DSG thus includes carbon dioxide along with the steam from water vaporization and the combustion to limit water replenishing requirements. The carbon dioxide may enhance hydrocarbon recovery and provide another advantage over the OTSG. However, the DSG can only provide a narrow range of carbon dioxide concentrations and other ranges may be more effective.

[0005] Therefore, a need exists for systems and methods that are cost efficient to generate steam with desired concentrations of carbon dioxide.

SUMMARY OF THE INVENTION

[0006] In one embodiment, a method of recovering hydrocarbons with steam includes generating the steam with combustion to heat and vaporize water and injecting into a formation the steam and carbon dioxide. The method further includes producing a mixture including the hydrocarbons, condensate of the steam and a portion of the carbon dioxide.

Supplying flow of the carbon dioxide sustains the injecting by recovering the carbon dioxide from the mixture produced and capturing less than 50 percent of carbon dioxide content within exhaust from the combustion.

[0007] According to one embodiment, a method of recovering hydrocarbons with steam includes producing the steam in an air-fired steam generator and injecting into a formation the steam and carbon dioxide that is injected at a rate between 1 and 25 percent of the steam by mass and is recovered from production fluids and separated from other exhaust constituents of the steam generator. Capture of carbon dioxide content within exhaust from the steam generator is relied on to maintain the rate given retention of a portion of the carbon dioxide in the reservoir. In addition, the method includes recovering the production fluids including the hydrocarbons.

[0008] For one embodiment, a system for recovering hydrocarbons with steam includes a steam generator that heats water with combustion to produce the steam. At least one injection well couples to the steam generator for introducing the steam and carbon dioxide into a formation while at least one production well recovers from the formation a mixture including the hydrocarbons, condensate of the steam and a portion of the carbon dioxide. A carbon dioxide supply couples to the at least one injection well for providing the carbon dioxide that is recovered from the mixture produced and captured from less than 50 percent of carbon dioxide content within exhaust from the combustion.

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.

[0010] Figure 1 depicts a schematic of a hydrocarbon recovery system including a steam generator with flue gas exhaust coupled to a carbon dioxide recovery unit for injection of steam and carbon dioxide both from the recovery unit and separated from recovered production fluids, according to one embodiment of the invention.

[0011] Figure 2 depicts a schematic of a hydrocarbon recovery system including an oxy-fired boiler and an exhausted steam generator for injection of steam and carbon dioxide both from flue gas exhaust of the oxy-fired boiler and separated from recovered production fluids, according to one embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0012] Embodiments of the invention relate to systems and methods of recovering hydrocarbons by injecting into a reservoir steam along with carbon dioxide recovered from flue gases produced while generating the steam and from separation of produced fluids. Due to benefits from the carbon dioxide injection, carbon dioxide capture rates from the flue gases selected below fifty percent in such combined recovery of the carbon dioxide enables lower fuel consumption even given that additional fuel is needed for the carbon dioxide capture versus steam only operations. As the capture rates from the flue gases increase above fifty percent like when employed for sequestration purposes, such approaches use more fuel than the steam only operations and may not be cost efficient. A carbon dioxide recovery unit coupled to an air-fired boiler or an auxiliary oxy-fired boiler may supply the carbon dioxide recovered from the flue gases.

[0013] Figure 1 illustrates a system for recovering hydrocarbons that includes a processing unit 102, an air-fired steam generator 116 and a carbon dioxide (CO2) recovery unit 110 that are all coupled to at least one production well 100 and at least one injection well 124. In an exemplary embodiment, the injection well 124 and the production well 100 provide a well pair for a steam assisted gravity drainage (SAGD) operation. Various other recovery operations including cyclic steam stimulation, solvent aided SAGD and steam drive may also employ processes described herein.

[0014] In operation, the processing unit 102 receives a mixture that is recovered from the production well 100 and includes hydrocarbons or oil, condensate from steam that is injected to heat and mobilize the oil and some carbon dioxide injected with the steam. The processing unit 102 may include liquid-gas separators, water-oil separators, treatment equipment for gas and water, and compression equipment for gas. The processing unit 102 separates the mixture into a sales stream 104 of the oil, a steam generator feed stream 106 of water and a gas recycle stream 108 of the carbon dioxide. The gas recycle stream 108 conveys the carbon dioxide that is recovered in the processing unit 102 back to the injection well 124 for introducing into the formation.

[0015] Recovery of the carbon dioxide from produced fluids at the processing unit 102 costs less than recovering the carbon dioxide in flue streams that are majority nitrogen or providing an air separation unit for oxy-combustion to limit the nitrogen in such flue streams. In some embodiments, at least 90, 95, 99 or 100 percent of the carbon dioxide in the produced fluids is recycled for injection into the formation. Embodiments described herein thus utilize the carbon dioxide recovered from the produced fluids along with the carbon dioxide recovered at rates less than fifty percent of total carbon dioxide output from generation of the steam that is injected. In contrast to other approaches that produce carbon dioxide for offsite sequestration, such partial capture makes up for reservoir retention to maintain a desired carbon dioxide injection rate without requiring excess additional capture.

[0016] The steam generator 116 burns fuel, such as natural gas, in air to heat and vaporize the water input via the feed stream 106. Exhaust combustion gases exit from the steam generator 116 separate from a steam output 122 that conveys resulting vaporized water to the injection well 124. A boiler or once through steam generator (OTSG) may provide the steam generator 116.

[0017] At least part of the combustion gases from the steam generator 116 pass to the CO2 recovery unit 110. A concentrated carbon dioxide stream 114 exits the CO2 recovery unit 110 and is conveyed to the injection well 124 for injection with the steam output 122. In some embodiments, the carbon dioxide stream 114 contains at least 90 percent, 95 percent or 99 percent carbon dioxide by mass.

[0018] How much of the combustion gases that are diverted and/or sizing of the CO2 recovery unit 110 depends on both retention rate of the carbon dioxide in the reservoir and desired carbon dioxide injection concentration rather than selection for maximizing carbon dioxide emission avoidance. Increases in the retention rate of the carbon dioxide in the reservoir reduce the amount of the carbon dioxide produced and available for recycle, thereby requiring a higher capture in the CO2 recovery unit 110 for a given desired carbon dioxide injection concentration. Similarly, increasing the desired carbon dioxide injection concentration also raises amount of capture required in the CO2 recovery unit 110. In some embodiments, level of the carbon dioxide in injected fluids may range between 1 percent and 25 percent, greater than 15 percent or less than 5 percent of the steam by mass with the fluids including the steam and less than 10, 5 or 1 percent by mass other gases.

[0019] By way of example, the CO2 recovery unit 110 may utilize a selective amine solution to strip the carbon dioxide from other flue gas constituents by absorption of the carbon dioxide within the solution. The amine solution comes in direct contact with the combustion gases from the steam generator 116 in an absorber of the CO2 recovery unit 110. The other flue gas constituents pass through the absorber and may exit the CO2 recovery unit 110 as treated exhaust via a 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 CO2 recovery unit 110. For some embodiments, liberation of the carbon dioxide from the amine solution may occur with temperature increase and pressure reduction.

[0021] Figure 2 shows an alternative hydrocarbon recovery system including an oxy-fired boiler 216 to provide makeup carbon dioxide within flue gas output 214 instead of utilizing the CO2 recovery unit 110 in Figure 1. Combustion exhaust from the air-fired steam generator 116 may therefore release to the atmosphere. Other components identified in Figure 2 by like reference numbers to those identified in Figure 1 operate as described already herein.

[0022] In contrast to the air-fired steam generator 116, the oxy-fired steam generator 216 burns fuel, such as natural gas or methane, in oxygen to heat and vaporize the water input via the feed stream 106. An air separation unit (ASU) may supply the oxygen to the oxy-fired steam generator 216. The flue gas output 214 from the oxy-fired steam generator 216 thus outputs carbon dioxide and additional steam as products of combustion with less than 10, 5 or 1 percent other gases by mass conveyed to the injection well 124 separate from an auxiliary steam output 222 from the oxy-fired steam generator 216 that also conveys resulting vaporized water to the injection well 124.

[0023] Similar to sizing of the CO2 recovery unit 110, sizing of the oxy-fired steam generator 216 depends on both retention rate of the carbon dioxide in the reservoir and desired carbon dioxide injection concentration rather than selection for maximizing carbon dioxide emission avoidance. Increases in the retention rate of the carbon dioxide in the reservoir reduce the amount of the carbon dioxide produced and available for recycle, thereby requiring an increase in the production rate of the oxy-fired steam generator 216 relative to the air-fired steam generator 116 for a given desired carbon dioxide injection concentration. Similarly, increasing the desired carbon dioxide injection concentration also raises the production rate of the oxy-fired steam generator 216 relative to the air-fired steam generator 116.

[0024] Mixing of the steam output 122 and the recycle stream 108 with the carbon dioxide stream 114 from the CO2 recovery unit 110 or the flue gas output 214 of the oxy-fired steam generator 216 enables adjusting concentration range of carbon dioxide being injected. Such control of the carbon dioxide concentration in the steam being injected provides flexibility. For example, a production profile may call for a lower carbon dioxide injection concentration in early production stages and more in later stages, which may be accomplished by increasing over time the amount of the carbon dioxide sent to the injection well 124 via the recycle stream 108.

[0025] As shown in the following table, process modeling compared results associated with a steam only case and two exemplary cases (e.g., as shown in Figure 1) all for a 90,000 barrel per day SAGD facility having all electrical power generated by a natural gas-fired combined cycle (NGCC) plant. These three cases include generating all required steam with an OTSG without carbon dioxide capture, with partial capture of 32 percent of the carbon dioxide produced by the OTSG for 40 percent carbon dioxide retention in the reservoir, and with partial capture of 16 percent of the carbon dioxide produced by the OTSG for 20 percent carbon dioxide retention in the reservoir. Reservoir modeling shows that while such fractions of the injected carbon dioxide may be retained in the reservoir significant remaining amounts may return to the surface in the produced gas making recycling possible.

[0026] For this analysis, an ideal carbon dioxide injection rate selected corresponds to carbon dioxide at 11.4 percent of the steam by mass. This carbon dioxide concentration results in lowering the steam to oil ratio (SOR) from 2.5 to 2.125. Such reduction in the SOR derives from benefits associated with injecting the carbon dioxide with the steam, which benefits may include viscosity reduction of the hydrocarbons from dissolution with the carbon dioxide, insulating effects of the carbon dioxide or carbon dioxide pressure support.

	OTSG	OTSG with Partial CO2 Capture	
		40 Percent CO2 Retention	20 Percent CO2 Retention
SOR	2.5	2.125	2.125
Steam (tons per hour)			
Total	1488	1264	1264
CO2 Flowrates (tons per hour)			
Captured	0	58 (32 percent)	29 (16 percent)
Recycle	0	87	115
Total	0	144	144
Electrical Loads (megawatts)			
Facility base	92	92	92
CO2 recovery	0	2	1
CO2 compress	0	15	13
Total	92	109	106
Fuel Flowrates (tons per hour)			
OTSG	78	68	66
NGCC	15	18	18
Total	93	86	84
Relative usage	1	.92	.90
Green House Gas Emissions to Atmosphere (tons per hour)			
CO2 emissions	251	173	196

[0027] Relative fuel usage shown in the table compares total fuel used by being normalized to the steam only case without carbon dioxide capture. The relative fuel use in the partial capture cases range between 0.90-0.92, which represents reduction in fuel operating expense relative to the steam only case using the OTSG without any carbon dioxide capture. The partial capture application also still enables recovering some of the carbon dioxide produced such that carbon dioxide emissions may drop 22-31 percent in the partial capture application relative to the steam only case without any carbon dioxide capture.

[0028] The preferred embodiments of the invention have been disclosed and illustrated. However, the invention is intended to be as broad as defined in the claims below. 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 below and the description, abstract and drawings are not to be used to limit the scope of the invention.

CLAIMS

1. A method of recovering hydrocarbons with steam, comprising:

generating the steam with combustion to heat and vaporize water;

injecting into a formation the steam and carbon dioxide;

producing a mixture including the hydrocarbons, condensate of the steam and a portion of the carbon dioxide; and

supplying flow of the carbon dioxide for sustaining the injecting by recovering the carbon dioxide from the mixture produced and capturing less than 50 percent, such as between 1 and 50 percent, e.g. between 10 and 50 percent or between 25 and 50 percent (by mass or by volume), of carbon dioxide content within exhaust from the combustion.

2. The method of claim 1, wherein the steam is generated in an air-fired steam generator and the carbon dioxide content within the exhaust is separated from other gases of the exhaust.

3. The method of claim 1, wherein the steam is generated in an air-fired steam generator and the carbon dioxide content within the exhaust is separated from other gases of the exhaust such that the carbon dioxide injected is mixed with less than 10 percent, such as between 0.1 and 10 percent, e.g. between 1 and 10 percent or 5 and 10 percent, nitrogen by mass.

4. The method of claim 1, wherein an amine based absorption unit captures the carbon dioxide content within the exhaust.

5. The method of claim 1, wherein the steam is generated in an air-fired steam generator in which the carbon dioxide content in the exhaust thereof is released and an oxy-fired steam generator in which the carbon dioxide content in the exhaust thereof is used in the supplying of the flow of the carbon dioxide.

6. The method of claim 1, wherein the carbon dioxide is injected with the steam and at a rate between 1 and 25 percent of the steam by mass.

7. The method of claim 1, wherein the carbon dioxide that is injected is mixed with less than 10 percent, such as between 0.1 and 10 percent, e.g. between 1 and 10 percent or 5 and 10 percent, nitrogen by mass.

8. The method of claim 1, wherein the steam is generated in a once through steam generator.

9. The method of claim 1, wherein the injecting is into a well disposed in the formation for a steam assisted gravity drainage operation.

10. The method of claim 1, wherein less than 32 percent, such as between 1 and 32 percent, e.g. between 16 and 32 percent (by mass or volume), of the carbon dioxide content within the exhaust from the combustion is captured and a remainder is released to atmosphere.

11. A method of recovering hydrocarbons with steam, comprising:

producing the steam in an air-fired steam generator;

injecting into a formation the steam and carbon dioxide that is injected at a rate between 1 and 25 percent of the steam by mass and is recovered from production fluids and separated from other exhaust constituents of the steam generator such that capture of carbon dioxide content within exhaust from the steam generator is relied on to maintain the rate given retention of a portion of the carbon dioxide in the reservoir; and

recovering the production fluids including the hydrocarbons.

12. The method of claim 11, wherein the carbon dioxide is separated from the other exhaust constituents of the steam generator to provide the carbon dioxide mixed with less than 10 percent, such as between 0.1 and 10 percent, e.g. between 1 and 10 percent or 5 and 10 percent, nitrogen by mass.

13. The method of claim 11, wherein the carbon dioxide is separated from the other exhaust constituents of the steam generator with an amine based absorption unit.

14. The method of claim 11, wherein the carbon dioxide that is separated from the other exhaust constituents of the steam generator captures less than 50 percent, such as between 1 and 50 percent, e.g. between 10 and 50 percent or between 25 and 50 percent (by mass or by volume), of carbon dioxide content within the exhaust of the steam generator.

15. The method of claim 11, wherein up to 16 percent, such as between 1 and 16 percent, e.g. between 4 and 16 percent (by mass or volume), of the carbon dioxide content within the exhaust from the combustion is captured and a remainder is released to atmosphere.

16. A system for recovering hydrocarbons with steam, comprising:

a steam generator that heats water with combustion to produce the steam;

at least one injection well coupled to the steam generator for introducing the steam and carbon dioxide into a formation;

at least one production well to recover from the formation a mixture including the hydrocarbons, condensate of the steam and a portion of the carbon dioxide; and

a carbon dioxide supply coupled to the at least one injection well for providing the carbon dioxide that is recovered from the mixture produced and captured from less than 50 percent, such as between 1 and 50 percent, e.g. between 10 and 50 percent or between 25 and 50 percent (by mass or by volume), of carbon dioxide content within exhaust from the combustion.

17. The system of claim 16, wherein the steam generator includes an air-fired steam generator in which the carbon dioxide content in the exhaust thereof is released and an oxy-fired steam generator in which the carbon dioxide content in the exhaust thereof forms part of the carbon dioxide supply.

18. The system of claim 16, wherein the carbon dioxide supply includes an amine based absorption unit to capture the carbon dioxide content within the exhaust.

19. The system of claim 16, wherein the steam generator is a once through steam generator.

20. The system of claim 16, wherein the injection well and the production well form a steam assisted gravity drainage well pair.

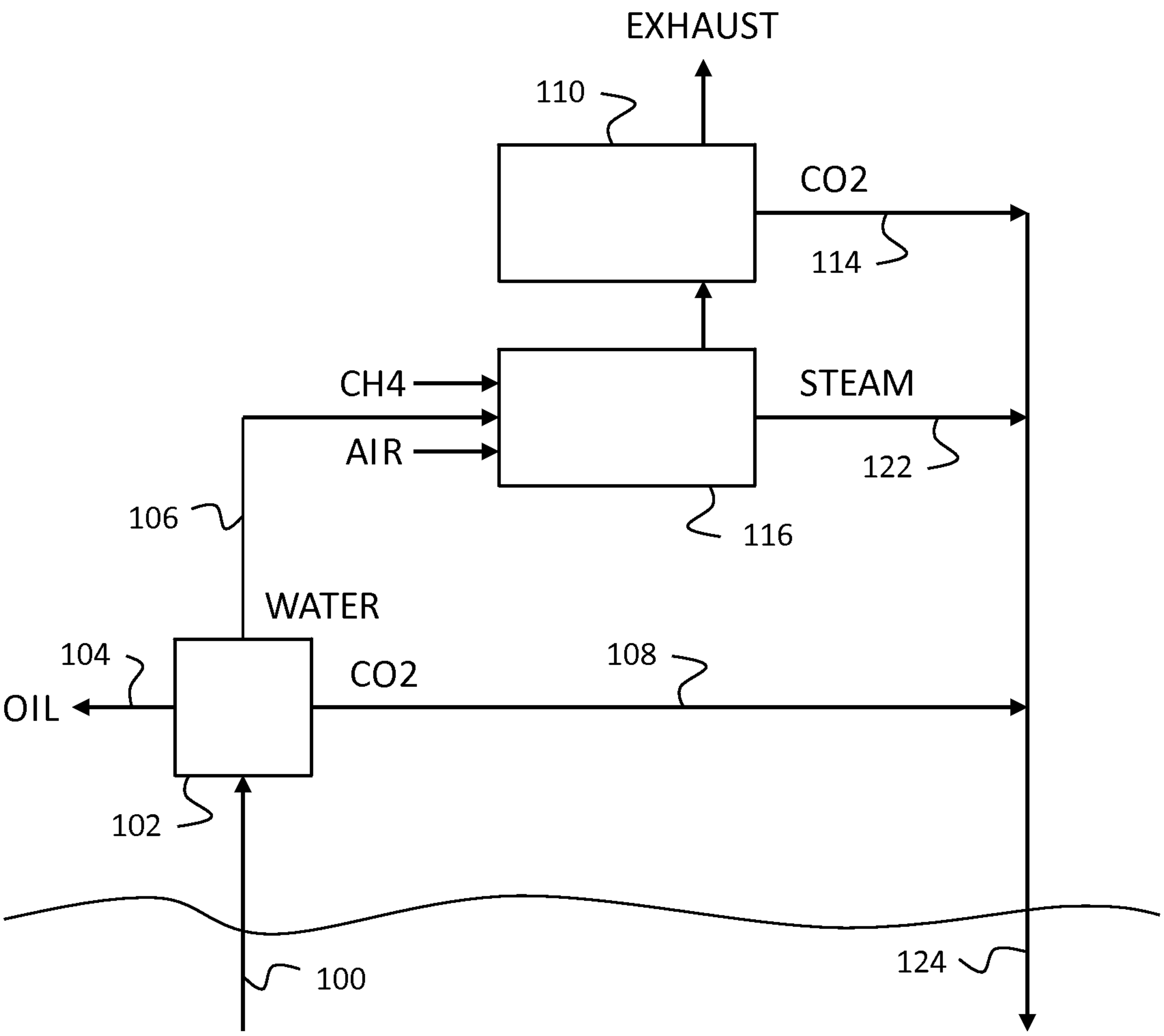
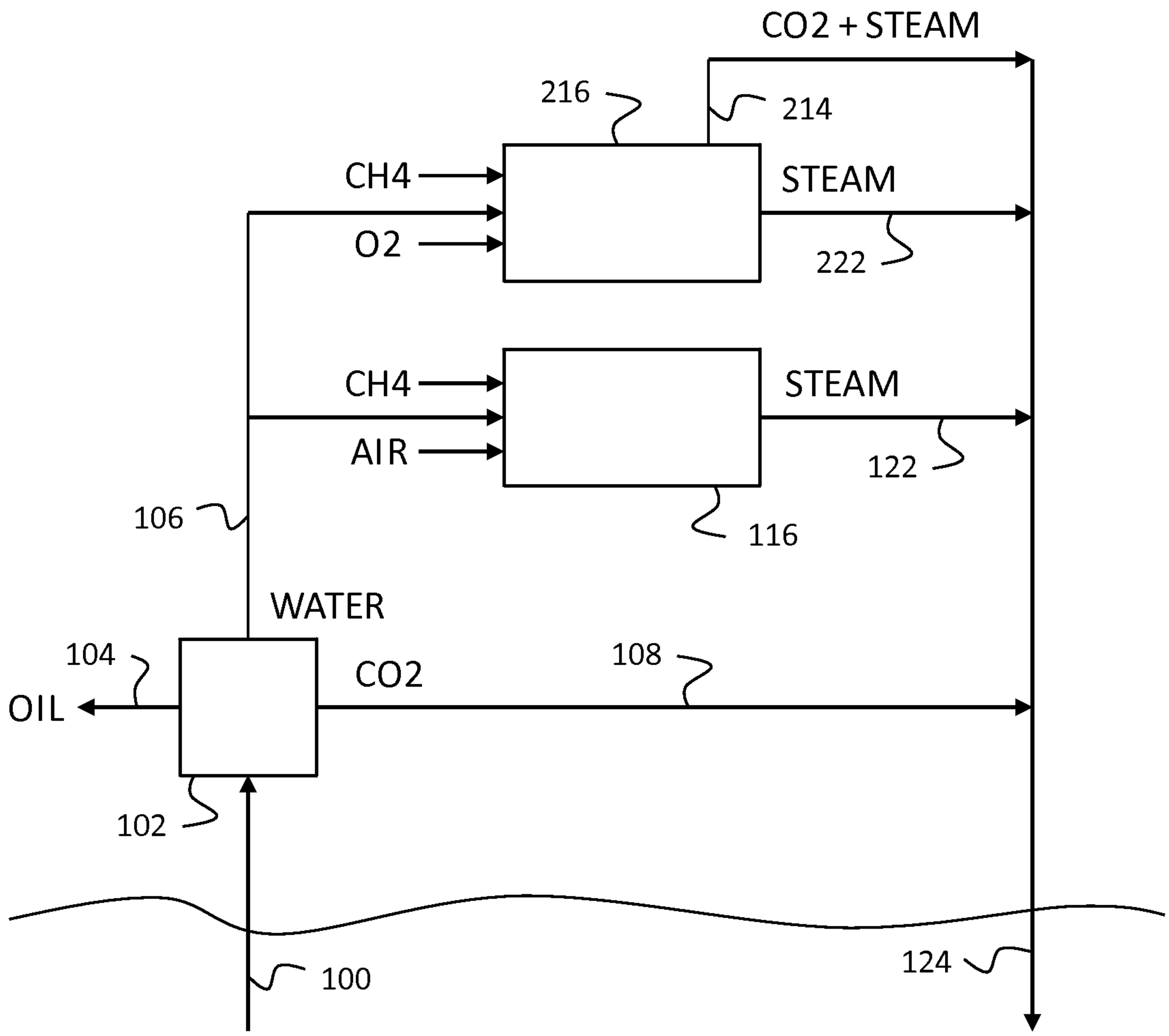

EXHAUST
110
CO2
114
CH4
STEAM
AIR
122
106
116
WATER
104
108
CO2
OIL
102
124
100

FIG. 1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STEAM
O2
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CH4
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122
106
116
WATER
104
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OIL
CO2
102
124
100

FIG. 2