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Feasibility study and process development of CO_2 EOR surface facilities

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ABSTRACT

This study presents process design of CO_2 EOR (Enhanced Oil Recovery) surface facilities and evaluation of their engineering feasibility. Two key functions for CO_2 EOR surface plants are i) CO_2 injection and ii) product separation. For product separation part, hydrocarbon products are recovered from the mixture produced from production wells which contain oil, brine, hydrocarbon gas, while CO_2 is separated for re-injection. For CO_2 injection part, CO_2 separated from the produced mixture is transferred through pipeline and pressurized with multiple compressor train for being re-injected to the reservoir. EOR surface plants require a series of separators, including 3-phase separator, dehydrator and NGL recovery unit, which are operated in an integrated and energy-efficient manner. The mixture produced from the well is initially separated into crude, brine and gas. Crude oil is sent to crude terminal and water is transferred to water injection satellites for Water-Alternating-Gas (WAG) injection process. Gas is dehydrated in molecular sieves dehydration units to control the water dew point for NGL (Natural Gas Liquids) recovery operation. A couple of columns are integrated with refrigeration cycle to recover C3+ component from gas and to separate CO_2. Process modeling and simulation for CO_2 EOR surface facilities has been carried out for evaluating their techno-economic performance.

1. Introduction

Recently, a great attention has been paid to CO_2 EOR (Enhanced Oil Recovery) in oil production, because of improved economics in oil production through increased oil production rate from EOR, as well as environmental contribution through sequestering CO_2 captured. It was estimated by US DOE (Department of Energy, 2015) that the potential market for CO_2 EOR is about 380 Tcf CO_2.

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However, the injected CO_2 is not fully stored within an oil reservoir and typically more than 50 % and up to 67% of injected CO_2 is produced together with oil and gas products (Global CCS Institute, 2011). Hence, surface facilities in CO_2 EOR requires recovery of CO_2 and reinjection them back to the well, with which CO_2 release to the atmosphere can be minimized as well as purchasing cost of additional CO_2 can be reduced. A schematic diagram for typical surface facilities for CO_2 EOR is illustrated in Figure 1, in which gas separation is only highlighted, and other infield facilities, water treatment, CO_2 compression and injection, etc. are omitted or simplified. Either molecular sieves or TEG (Tri-ethylene Glycol) unit can be selected for dehydration which controls water dew point for enabling downstream recovery processes. TEG unit is cheaper than molecular sieves, while molecular sieves are preferred when simplicity in the operation is desired.

After dehydration, the simultaneous recovery of CO_2 and hydrocarbon products is to be considered. Although technologies applicable for NGL production are well established in gas industries, for example, a wide range of turbo-expander processes by Ortloff®, conventional NGL processes is typically applied for pre-treated natural gas which contains very low or trace of CO_2. However, NGL recovery processes in CO_2 EOR should be made for the produced gas containing large amount of CO_2. As recovery and reinjection of CO_2 is also required for EOR, NGL recovery processes are to be integrated with CO_2 removal processes. Hence, we are investigating integrated processes which both NGL recovery and CO_2 recovery are made. Process modeling and simulation study for CO_2 EOR surface facilities has been carried out and techno-economic performance of two integrated processes are compared in this study.

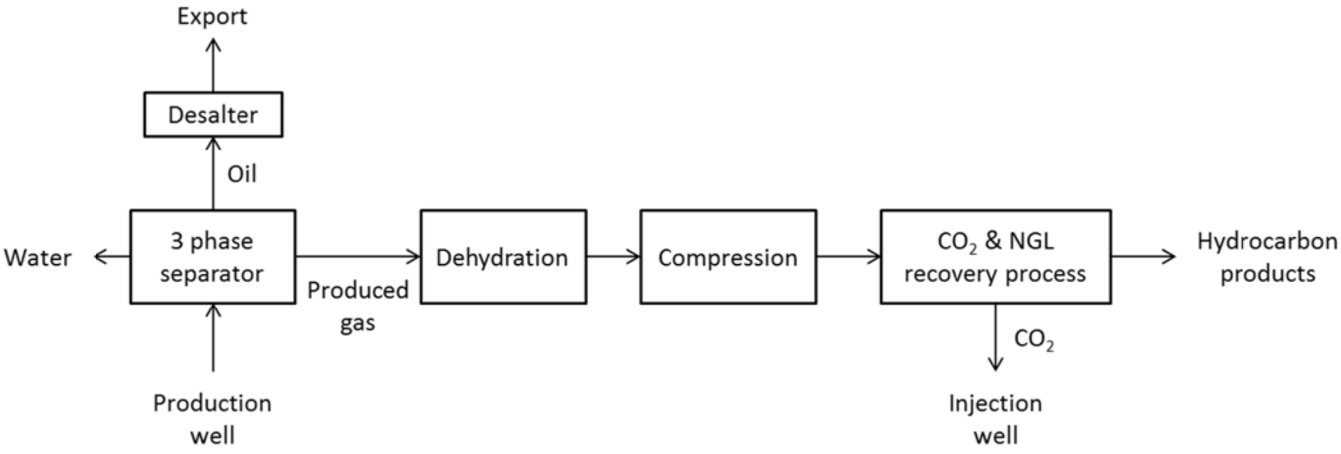

Figure 1. Typical surface facilities for CO2 EOR

2. Process Design

The amount of gas produced and CO_2 composition changes throughout the lifetime of CO_2 EOR project, and we selected the year in which maximum flowrate for gas is produced, as illustrated in Figure 2. Although operating conditions and compositions of produced gas is very site-specific, the current study is based on design basis of Kwak et al. (2014) as given in Table 1. Also product specifications are very different, depending on gas compositions, market situation and etc., typical product specifications has been drawn up as shown in Table 1. It should be noted that results and discussion made in this study has a certain degree of uncertainty in the design and their economic evaluation, because of wide range of differences in feed compositions and EOR field conditions.

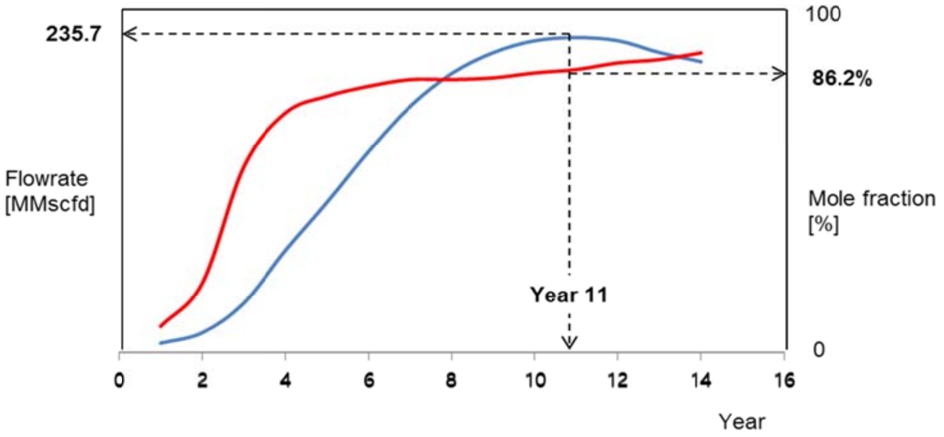

Figure 2. Typical yearly flowrate and CO_2 content of gas produced

<table>
<tr><th colspan="2">Feed gas conditions</th><th>Product Specification</th></tr>
<tr><td colspan="2">Temperature = 40 °C
Pressure = 20 bar(g)
Flowrate = 235.7 MMscfd</td><td rowspan="13">C1 product
- CO_2: max 3 mol %
- H_2S: max 4 ppm
- Heating value: 1000~1200 Btu/Scf
- Water content: max 7 lb/MMscf
- Pressure: 69 bar(g)

NGL product
- H2S: max 50 ppm
- C3+ recovery: min 95%

Conditions for CO2 reinjection
- Pressure: 172 bar(g)</td></tr>
<tr><td>Feed gas composition</td><td>Mole fraction (%)</td></tr>
<tr><td>C1</td><td>5.3</td></tr>
<tr><td>C2</td><td>2.9</td></tr>
<tr><td>C3</td><td>2.6</td></tr>
<tr><td>iC4</td><td>0.6</td></tr>
<tr><td>nC4</td><td>0.7</td></tr>
<tr><td>iC5</td><td>0.26</td></tr>
<tr><td>nC5</td><td>0.27</td></tr>
<tr><td>C6+</td><td>0.57</td></tr>
<tr><td>H_2S</td><td>0.6</td></tr>
<tr><td>CO2</td><td>86.2</td></tr>
<tr><td>H_2O</td><td>Saturated</td></tr>
</table>

Table 1. Feed conditions and product specifications (Kwak et al., 2014)

As the produced gas contains valuable hydrocarbons, it is desirable to consider NGL recovery processes together with CO_2 recovery process in surface facilities for CO_2 EOR. As sequences of and connectivity between unit operations for separating CO_2 and hydrocarbons can be varied, different potential configurations should be investigated to find the most appropriate flowsheet. The current study focuses on the recovery of CO_2 and NGL only, as other surface facilities can be designed by following conventional design concept. Two flowsheets for CO_2 and NGL recovery process were evaluated and compared:

- Case A: High purity CO_2 is recovered and re-injected, while C1 and C2+ are recovered as hydrocarbon products (Figure 3) (Kwak et al., 2014).

- Case B: C1 and C2 can be re-injected together with CO_2, while C3+ product is recovered as hydrocarbon products (Figure 4)

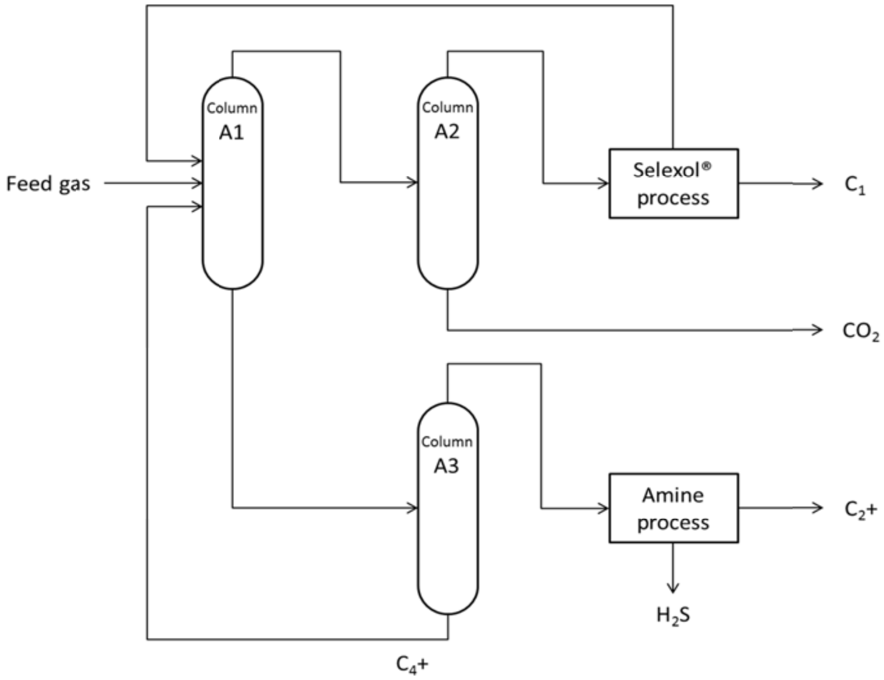

Figure 3. Flowsheet for NGL and CO_2 recovery process [Case A] (Kwak et al., 2014)

In this study, focus was made to evaluate the feasibility of two flowsheets above and compare their energy requirements. Amine, Selexol® and distillation processes are considered for the design of CO_2 and NGL recovery processes. Process modeling was carried out with UniSim®. Three fluid packages, namely, Amine, Glycol, and Peng−Robinson equation, are used to model three different CO_2 separation. The ambient temperature is assumed to be 30 °C and 10 °C of a minimum temperature approach for heat exchangers, except, 5 °C for refrigeration exchanger, is used. Also, a simple propane refrigeration cycle is used when refrigeration is needed for both cases. Unit cost of utility used in this study are US$7.63/ton for high pressure steam (available at 240°C), US$7.03/ton for low pressure steam (available at 180°C), US$0.005/kWh for cooling water, and US$0.05/kWh for electricity (Smith and Varbanov, 2005).

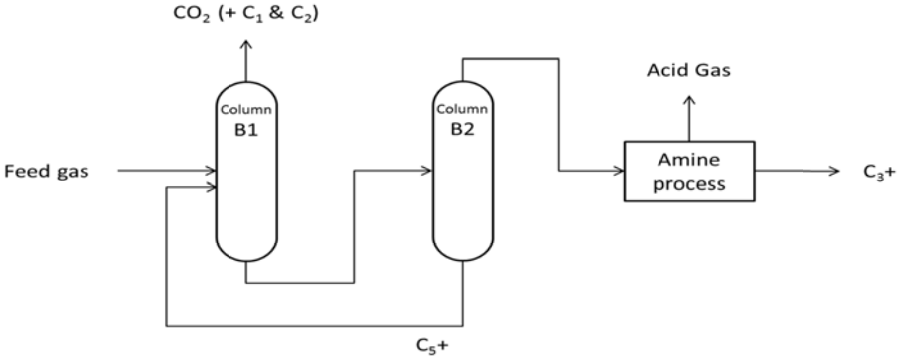

Figure 4. Flowsheet for NGL and CO_2 recovery process [Case B]

3. Technical comparison of CO_2 and NGL recovery configurations

Flowsheet of Case A was initially proposed by Kwak et al. (2014), which was evolved from 4-column Ryan/Holmes process. Case A strategically uses Selexol process which replaces some part of Ryan/Holmes process for the separation of methane or ethane from CO_2, while amine-based process is used to remove H_2S to give the NGL product. The amount of additive recycled to the ethane recovery column (A1 in Figure 3) becomes smaller, compared to conventional 4-column Ryan/Homes process, which leads to decreased energy consumption in the ethane recovery column (A1 in Figure 3) and additive recovery column (A3 in Figure 3).

Product		Case A	Case B
C1 product	Flowrate [kmol/h]	641.8	-
	C1 composition [mol%]	96.66	-
NGL product	Flowrate [kmol/h]	866.9	626.9
	C2 recovery [%]	90.02	-
	C3 recovery [%]	95.50	95.49
CO_2 Recovered	Flowrate [kmol/h]	10119.1	11086.3
	CO_2 composition [mol%]	99.46	90.94
	CO_2 recovery [%]	99.74	99.90
Energy Consumption	HP steam (240 °C) [MW]	67.4	10.8
	LP steam (180 °C) [MW]	144.5	12.6
	Refrigeration [MW]	113.7	17.4
	Cooling water [MW]	157.2	51.9
	Shaft power [MW]	13.6	18.7

Table 2. Comparison of two processes' performance

However, flowrate of recycling stream from Column A3 to Column A1 is about up to 150% of feed gas flowrate, which still contributes considerable consumption of energy and high capital expenditure. Hence, rather attempting to separate CO_2 from C2, alternative configuration (Case B) can be proposed to recover C3+ product only from the produced gas and to reject C1 and C2 together with CO_2. The first column (B1 in Figure 4) is used for recovering C3+ and C3+ bottom product is produced with acid gases. C5+ bottom product from Column B2 is recycled back to Column B1, while acid gases are separated through amine process. Configuration of Case B can be designed with considerably small flowrate of recycle stream, compared to Case A. This small recycle flowrate allows significant reductions in utility consumptions for both steam and refrigeration.

The performance of the CO_2 and NGL recovery processes and their energy consumption for Cases A and B are shown in Table 2. Except shaft power requirement, great potential for saving energy consumptions has been observed by producing only C3+ NGL product from surface facilities, which is an important decision factor in determining the most appropriate flowsheet of CO_2 recovery processes. It should be noted that CO_2 stream recovered from Case B may contain more H_2S than allowed for reinjection in CO_2 EOR,

4. Conclusions

Two configurations for separating CO_2 and recovering NGL products from produced gas in CO_2 EOR applications have been presented in this study. Process simulation is made for these two cases, which were then evaluated from the viewpoint of energy consumption. It would be ideal to compare capital costs for both cases, although authors leave this task as future work.

From the case study conducted above, recovering CO_2 together with C1 and C2 can be an economically viable option because energy consumptions can be reduced and smaller equipment can be accommodated. However, techno-economic performance of flowsheets compared in this study is strongly dependent on produced gas conditions, product specifications and needs for NGL products. Hence, the effectiveness of each design should be judged for a range of different operating conditions and design basis.

Acknowledgement

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