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Synthesis of Energy Efficient Cryogenic Distillation Networks for Maximum Methane Recovery from Natural Gas with Carbon Dioxide and Heavy Hydrocarbons

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ABSTRACT

A study was conducted with different configurations of cryogenic distillation networks to remove carbon dioxide from natural gas feed with high heavy hydrocarbon content. Single stage separators were added to facilitate the initial removal of heavy hydrocarbons and carbon dioxide. Three different case studies along with the conventional cryogenic network have been investigated. Thermodynamic behavior of $\text{CH}_4\text{-CO}_2$ mixture was analyzed to synthesize appropriate network configuration at higher pressures. The effect of number of separators, their positions and operating conditions on energy requirement, methane recovery and final purity of methane was studied. A considerable reduction in energy has been reported for case studies 1, 2 and 3 over case study 0 (conventional distillation network). Indicative profit index was formulated and calculated for the each case study.

Key words: Cryogenic distillation network, CO_2 separation, energy requirements, natural gas with heavy hydrocarbons

INTRODUCTION

Natural gas is one of the most useful and utilized energy sources of the world. Water, sand, carbon dioxide, hydrogen sulfide, wax, higher hydrocarbons, natural gas liquids and mercury are present along with the methane as impurities (Speight, 2007). Removal of sulfur dioxide and heavy hydrocarbons from natural gas has been extensively reported in literature but recovery of methane from natural gas having high content of carbon dioxide and higher hydrocarbons has not yet been fully reported in the research literature. Some natural gas reserves have CO_2 content upto 80% and considerable efforts are needed for the removal of carbon dioxide to make these reserves accessible. With the increase in energy demand, development of a process to remove carbon dioxide from the natural gas at higher pressures without using any external chemicals is getting attention. In Malaysia, enormous amount of natural gas is undeveloped because of the high concentration of CO_2 often exceeding 70 mole% (Darman and Harum, 2006).

In the present study, Malaysian natural gas containing moderate CO_2 (30%) and high heavy hydrocarbon (about 20%) contents has been purified using a network of cryogenic distillation columns with different column arrangements and operating conditions.

Cryogenic distillation also enables direct production of liquid CO_2 and transportation through pipeline. It is considered as one of the most capable method of CO_2 separation from CH_4 . Cryogenic distillation is an energy intensive process and efforts are needed to find combinations between equipment, product purity, methane losses and energy requirement. Thermodynamic phase behavior of methane and carbon dioxide mixture is complicated at lower temperatures and has been reported and analyzed in literature (Davis *et al.*, 1962; Donnelly and Katz, 1954; Li *et al.*, 2011). Solidification of CO_2 along with vapor liquid equilibrium in the distillation column causes operational problem and needs attention during the process.

Different cryogenic processes for the separation of CO_2 from natural gas have already been developed. Holmes and

Ryan (1982) developed an extractive distillation by adding heavier hydrocarbon (typically C_2 - C_5) in the condenser of the distillation column to avoid carbon dioxide solidification (Holmes *et al.*, 1983). A three distillation column network was simulated by using C_5 as an additive in ASPEN Hysys for the separation of CO_2 from natural gas (Berstad *et al.*, 2012). A hybrid cryogenic distillation network is also reported in the literature (Mullick *et al.*, 2013). Denton and Valencia (1983) used helium as additive to facilitate the separation of CO_2 from methane and avoiding the carbon dioxide solidification, however, the separation of He from CH_4 at higher pressure is quite problematic. A dual pressure distillation process for the removal of carbon dioxide from natural gas was introduced by Atkinson *et al.* (1988) to remove high concentration of carbon dioxide from methane which comprises of two distillation columns operating at different pressures to avoid carbon dioxide solidification. The overhead product of second column produces methane for pipeline specification but the pressures of these columns must be carefully selected to avoid CO_2 solidification. Process information is hardly available for further development or commercialization of this process. A two stage compression, refrigeration and separation process has been developed for the liquefaction and separation of carbondioxide (Xu *et al.*, 2012). Higher exergy losses are present and almost 90% CO_2 can be separated. Some recently reported (Clodic *et al.*, 2005; Song *et al.*, 2012; Willems *et al.*, 2010) cryogenic CO_2 removal technologies, comprise of mechanical methods to separate the CO_2 rich phase from the natural gas. A process of C3sep (condensed contaminant centrifugal separation), in which CO_2 is condensed into droplets and then separated from the natural gas using rotational separators (Willems *et al.*, 2010).

Most of the previous study for cryogenic distillation has been carried out for the conventional distillation scheme and no other configurations have been available in the literature. Furthermore the other cryogenic processes, except cryogenic distillation, are also either energy extensive or do not give required separation of carbon dioxide from natural gas especially at higher pressures. Under higher pressures, it becomes important to study and analyze the thermodynamic options available for the separation of CH_4 and CO_2 . Figure 1 provides the solid phase prediction on the phase envelope of different composition of CH_4 - CO_2 mixture. It is evident from Fig. 1 that at higher concentration of CO_2 , the separation is possible at higher pressures. As in the case of 80 and 60% carbon dioxide, the column can be operated smoothly even at 70 bar pressure. With the decrease in concentration of carbon dioxide, the vapor-liquid zone becomes smaller and column operation at higher pressure results in the thermodynamic conditions containing of both liquid and solid. It is observed from Fig. 1 that the V-L zone under lower CO_2 concentration in the mixture comes alarmingly closer to the three phase locus.

The objective of the present study is to synthesize cryogenic separation network and reduce energy expenditure through use of alternate networks and suitable operating conditions.

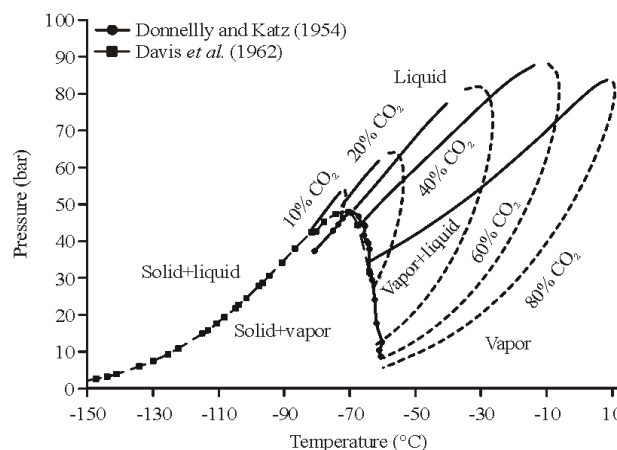


Fig. 1: Solid phase prediction on the phase envelope of CH_4 - CO_2 mixture

Table 1: Feed composition (mole fraction) for natural gas with higher hydrocarbons

| Hydrocarbons | Values |
|---------------|--------|
| CH_4 | 0.46 |
| C_2H_6 | 0.04 |
| C_3H_8 | 0.04 |
| $n-C_4H_{10}$ | 0.04 |
| $i-C_4H_{10}$ | 0.03 |
| $n-C_5H_{12}$ | 0.03 |
| $i-C_5H_{12}$ | 0.03 |
| C_6H_{14} | 0.02 |
| CO_2 | 0.30 |
| N_2 | 0.01 |

For this study, three different configurations of distillation column networks with single stage separators at different pressure and temperature conditions along with the conventional distillation scheme are simulated and the energy requirements, percentage recovery of methane and average product purity in each case study has been presented. Finally, indicative profit index has been formulated from weighted average values of quality and energy requirements (Basak *et al.*, 2002).

MATERIALS AND METHODS

In the present study, simulation studies have been carried out for different network configurations of distillation and single stage separators. The feed composition is provided in Table 1 with a flow rate of $10000 \text{ kmol h}^{-1}$. Three different case studies were conducted along with one base case for different column configuration and different operating pressures. These are represented by Fig. 2a-d. The energy requirements, average methane purity and methane losses in the each case study were calculated and compared with the base case in Fig. 2a which is case study 0. For case studies 1, 2 and 3 first distillation column was replaced with a single stage separator (C_1) at 60 bar and 10°C . For case studies 2 and 3 a second separator was also added at different positions. The pressure in the second separator and distillation columns was

kept same in case study 2. In case study 3 the pressure and temperature conditions for second separator (C_2) were fixed at 50 bars and -40°C . Pressure and temperature conditions

selected in the separators were based on the detailed analysis of thermodynamics of natural gas mixture and flash calculation's results.

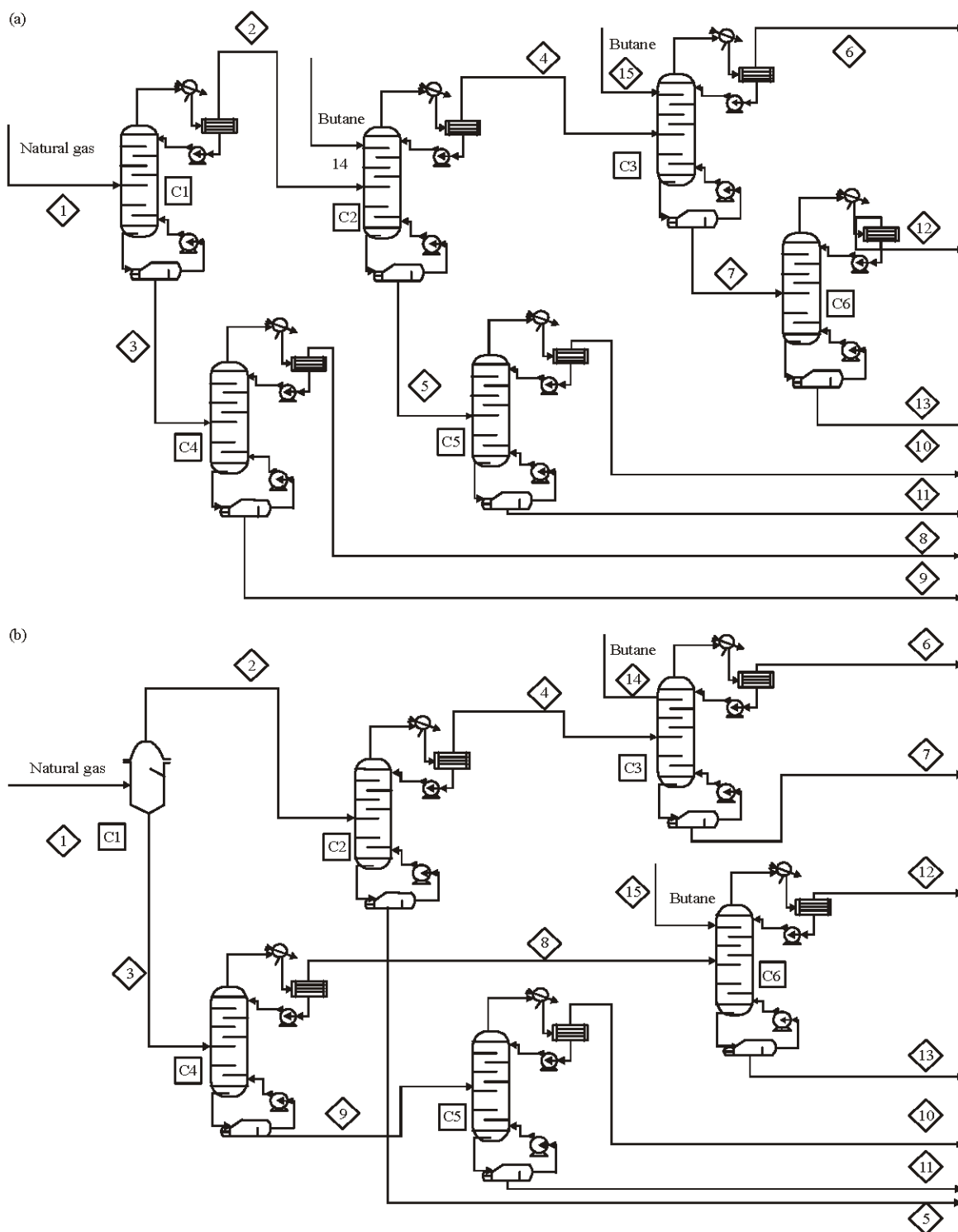


Fig. 2(a-d): Continue

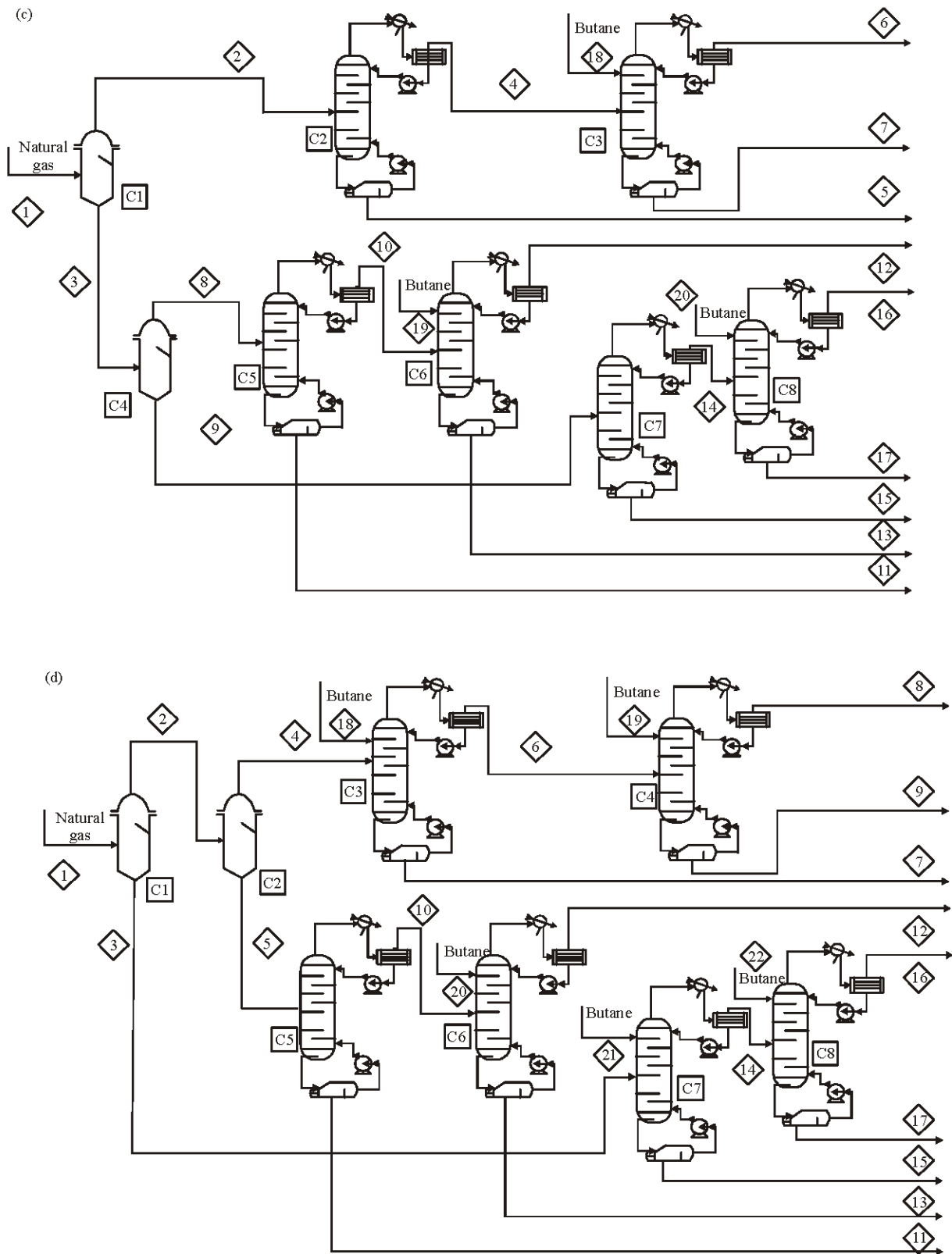


Fig. 2(a-d): Purification of natural gas (a) Base case study: Case study 0, (b) Case study 1, (c) Case study 2 and (d) Case study 3

Butane as an additive was added in the distillation columns to avoid the CO₂ solid formation by comparing the stage conditions with the experimental data of vapor-liquid-solid equilibrium available in the literature (Davis *et al.*, 1962; Donnelly and Katz, 1954). The simulation is carried out at 40 and 50 bar for all the case studies.

For case studies 2 and 3 the number of distillation columns were increased from six to eight to get the methane purity near to the other case studies.

RESULTS AND DISCUSSION

In case study 0, stream 5 is the only methane rich stream as shown in Table 2. At 50 bar it contains 96% of methane along with 2% nitrogen and carbon dioxide each. Stream 9 contains most of the heavy hydrocarbons and carbon dioxide is present in stream 8, 10 and 12. The composition for natural gas components for case study 1 is presented in Table 3, methane is present in streams 6 and 12 and heavy hydrocarbons are leaving in stream 11. Carbon dioxide is

present in streams 5, 7, 10 and 13. Butane is also present in stream 7, 10 and 13 along with carbon dioxide. Table 4 represents the simulation results of case study 2, where streams 6, 12 and 16 contains methane and carbon dioxide is distributed in streams 5, 7, 10 and 13. Stream 15 contains heavy hydrocarbons. For case study 3, methane is present in streams 6, 12, 16, 17 as given in Table 5. From Table 6, it is evident that decrease in pressure increases the energy requirements. The overall recovery and purity of methane increases in all the case studies by decreasing the column pressure. Case study 0 shows the maximum recovery and purity of methane. The heavy hydrocarbons and carbon dioxide recovery is also maximum in case study 0. The energy requirements for case study 0 with conventional distillation scheme is almost twice as compared to the other case studies as shown in Table 6. Case study 3 has the lowest energy requirements but a significant decrease in purity and recovery of methane which can be observed for this case study in Table 6. For case study 1, with one separator the purity and recovery of methane is almost same but the energy

Table 2: Tabulation of stream composition for case study 0

| Stream No. | Component mole fraction | | | | | | | | | |
|---------------|-------------------------|-------------------------------|-------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|--------------------------------|-----------------|----------------|
| | CH ₄ | C ₂ H ₆ | C ₃ H ₈ | n-C ₄ H ₁₀ | i-C ₄ H ₁₀ | n-C ₅ H ₁₂ | i-C ₅ H ₁₂ | C ₆ H ₁₄ | CO ₂ | N ₂ |
| 50 bar | | | | | | | | | | |
| 6 | 0.96 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 |
| 8 | 0.00 | 0.07 | 0.04 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.88 | 0.00 |
| 9 | 0.00 | 0.04 | 0.16 | 0.19 | 0.13 | 0.14 | 0.14 | 0.09 | 0.13 | 0.00 |
| 10 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.89 | 0.00 |
| 11 | 0.00 | 0.04 | 0.02 | 0.77 | 0.00 | 0.00 | 0.00 | 0.00 | 0.16 | 0.00 |
| 12 | 0.00 | 0.09 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.90 | 0.00 |
| 13 | 0.00 | 0.06 | 0.00 | 0.72 | 0.00 | 0.00 | 0.00 | 0.00 | 0.22 | 0.00 |
| 40 bar | | | | | | | | | | |
| 6 | 0.98 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 |
| 8 | 0.00 | 0.05 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.93 | 0.00 |
| 9 | 0.00 | 0.03 | 0.17 | 0.19 | 0.14 | 0.14 | 0.14 | 0.09 | 0.12 | 0.00 |
| 10 | 0.00 | 0.11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.89 | 0.00 |
| 11 | 0.00 | 0.03 | 0.02 | 0.79 | 0.00 | 0.00 | 0.00 | 0.00 | 0.16 | 0.00 |
| 12 | 0.01 | 0.11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.88 | 0.00 |
| 13 | 0.00 | 0.08 | 0.00 | 0.67 | 0.00 | 0.00 | 0.00 | 0.00 | 0.26 | 0.00 |

Table 3: Tabulation of stream composition for case study 1

| Stream No. | Component mole fraction | | | | | | | | | |
|---------------|-------------------------|-------------------------------|-------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|--------------------------------|-----------------|----------------|
| | CH ₄ | C ₂ H ₆ | C ₃ H ₈ | n-C ₄ H ₁₀ | i-C ₄ H ₁₀ | n-C ₅ H ₁₂ | i-C ₅ H ₁₂ | C ₆ H ₁₄ | CO ₂ | N ₂ |
| 50 bar | | | | | | | | | | |
| 5 | 0.00 | 0.05 | 0.08 | 0.04 | 0.04 | 0.02 | 0.02 | 0.00 | 0.74 | 0.00 |
| 6 | 0.96 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 |
| 7 | 0.02 | 0.08 | 0.00 | 0.44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.45 | 0.00 |
| 10 | 0.06 | 0.10 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.81 | 0.00 |
| 11 | 0.00 | 0.04 | 0.14 | 0.20 | 0.14 | 0.17 | 0.16 | 0.12 | 0.04 | 0.00 |
| 12 | 0.94 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.01 |
| 13 | 0.01 | 0.08 | 0.00 | 0.45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.46 | 0.00 |
| 40 bar | | | | | | | | | | |
| 5 | 0.00 | 0.03 | 0.08 | 0.04 | 0.04 | 0.02 | 0.02 | 0.00 | 0.76 | 0.00 |
| 6 | 0.98 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 |
| 7 | 0.00 | 0.10 | 0.00 | 0.44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.45 | 0.00 |
| 10 | 0.03 | 0.09 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.86 | 0.00 |
| 11 | 0.00 | 0.04 | 0.14 | 0.19 | 0.14 | 0.16 | 0.16 | 0.11 | 0.06 | 0.00 |
| 12 | 0.98 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |
| 13 | 0.01 | 0.09 | 0.00 | 0.45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.44 | 0.00 |

Table 4: Tabulation of stream composition for case study 2

| Stream No. | Component mole fraction | | | | | | | | | |
|---------------|-------------------------|-------------------------------|-------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|--------------------------------|-----------------|----------------|
| | CH ₄ | C ₂ H ₆ | C ₃ H ₈ | n-C ₄ H ₁₀ | i-C ₄ H ₁₀ | n-C ₅ H ₁₂ | i-C ₅ H ₁₂ | C ₆ H ₁₄ | CO ₂ | N ₂ |
| 50 bar | | | | | | | | | | |
| 5 | 0.00 | 0.05 | 0.08 | 0.04 | 0.04 | 0.02 | 0.02 | 0.00 | 0.74 | 0.00 |
| 6 | 0.96 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 |
| 7 | 0.02 | 0.08 | 0.00 | 0.44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.45 | 0.00 |
| 11 | 0.04 | 0.07 | 0.11 | 0.06 | 0.06 | 0.03 | 0.03 | 0.01 | 0.59 | 0.00 |
| 12 | 0.94 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.01 |
| 13 | 0.07 | 0.08 | 0.01 | 0.35 | 0.00 | 0.00 | 0.00 | 0.00 | 0.49 | 0.00 |
| 15 | 0.04 | 0.05 | 0.10 | 0.15 | 0.11 | 0.13 | 0.13 | 0.10 | 0.19 | 0.00 |
| 16 | 0.93 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.01 |
| 17 | 0.21 | 0.07 | 0.01 | 0.23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.48 | 0.00 |
| 40 bar | | | | | | | | | | |
| 5 | 0.00 | 0.03 | 0.08 | 0.04 | 0.04 | 0.02 | 0.02 | 0.00 | 0.76 | 0.00 |
| 6 | 0.98 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 |
| 7 | 0.00 | 0.10 | 0.00 | 0.44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.45 | 0.00 |
| 11 | 0.05 | 0.07 | 0.09 | 0.05 | 0.04 | 0.02 | 0.02 | 0.00 | 0.65 | 0.00 |
| 12 | 0.96 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.01 |
| 13 | 0.01 | 0.10 | 0.00 | 0.43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.46 | 0.00 |
| 15 | 0.01 | 0.05 | 0.11 | 0.16 | 0.11 | 0.14 | 0.14 | 0.10 | 0.17 | 0.00 |
| 16 | 0.95 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.01 |
| 17 | 0.12 | 0.09 | 0.00 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.54 | 0.00 |

Table 5: Tabulation of stream composition for case study 3

| Stream No. | Component mole fraction | | | | | | | | | |
|---------------|-------------------------|-------------------------------|-------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|--------------------------------|-----------------|----------------|
| | CH ₄ | C ₂ H ₆ | C ₃ H ₈ | n-C ₄ H ₁₀ | i-C ₄ H ₁₀ | n-C ₅ H ₁₂ | i-C ₅ H ₁₂ | C ₆ H ₁₄ | CO ₂ | N ₂ |
| 50 bar | | | | | | | | | | |
| 7 | 0.01 | 0.07 | 0.02 | 0.38 | 0.00 | 0.00 | 0.00 | 0.00 | 0.52 | 0.00 |
| 8 | 0.96 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.03 |
| 9 | 0.21 | 0.02 | 0.00 | 0.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.27 | 0.00 |
| 11 | 0.01 | 0.07 | 0.08 | 0.05 | 0.04 | 0.02 | 0.02 | 0.01 | 0.71 | 0.00 |
| 12 | 0.96 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.01 |
| 13 | 0.05 | 0.09 | 0.00 | 0.44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.42 | 0.00 |
| 15 | 0.02 | 0.06 | 0.10 | 0.16 | 0.09 | 0.11 | 0.10 | 0.08 | 0.28 | 0.00 |
| 16 | 0.96 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.01 |
| 17 | 0.03 | 0.05 | 0.00 | 0.42 | 0.00 | 0.00 | 0.00 | 0.00 | 0.50 | 0.00 |
| 40 bar | | | | | | | | | | |
| 7 | 0.00 | 0.06 | 0.02 | 0.38 | 0.00 | 0.00 | 0.00 | 0.00 | 0.53 | 0.00 |
| 8 | 0.97 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 |
| 9 | 0.19 | 0.02 | 0.00 | 0.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.28 | 0.00 |
| 11 | 0.00 | 0.06 | 0.09 | 0.05 | 0.04 | 0.02 | 0.02 | 0.01 | 0.72 | 0.00 |
| 12 | 0.98 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |
| 13 | 0.04 | 0.12 | 0.00 | 0.44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.41 | 0.00 |
| 15 | 0.01 | 0.06 | 0.10 | 0.16 | 0.09 | 0.11 | 0.10 | 0.08 | 0.29 | 0.00 |
| 16 | 0.98 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |
| 17 | 0.07 | 0.05 | 0.00 | 0.42 | 0.00 | 0.00 | 0.00 | 0.00 | 0.47 | 0.00 |

Table 6: Energy requirement and recovered CH₄

| Case study No. | Pressure bar | Avg. CH ₄ purity (mol%) | Recovered CH ₄ (%) | Energy (MW) | Normalized profit index (indicative) |
|----------------|--------------|------------------------------------|-------------------------------|-------------|--------------------------------------|
| 0 | 40 | 97.70 | 99.90 | 151.98 | 0.77 |
| | 50 | 95.62 | 99.70 | 135.44 | 0.63 |
| 1 | 40 | 97.56 | 99.25 | 80.23 | 0.80 |
| | 50 | 96.15 | 98.68 | 71.66 | 0.73 |
| 2 | 40 | 97.29 | 98.34 | 67.96 | 0.73 |
| | 50 | 96.10 | 95.78 | 60.80 | 0.64 |
| 3 | 40 | 97.12 | 95.22 | 72.60 | 0.70 |
| | 50 | 95.96 | 94.08 | 65.59 | 0.63 |

requirements are half of the conventional distillation scheme. To get pure carbon dioxide in case study 1, further processing of streams 5, 10 and 13 is needed. Case study 2 gives almost the same energy requirement as of the case study 1. The

methane losses increases and purity decreases in this configuration. Increase in number of distillation columns were needed in case studies 2 and 3 to get a comparative purity and recovery of methane. Table 6 shows that maximum recovery

and purity of methane is possible in case study 1. Further processing of streams are needed to get pure carbon dioxide in case studies 1, 2 and 3. Methane purity reaches maximum at 40 bars for all the case studies but the energy requirement is also on the higher side for the lower pressures. Indicative profit index has been formulated by using the following equation:

$$\text{Normalized profit index } (\phi) = \frac{\text{If } \text{flag} \times \text{Recovery of H/C} \times \text{H/C sales prices} - \text{Energy} \times \text{Energy cost}}{\text{Maximum theoretical profit}}$$

The profit index was found to be maximum for the case study 1 at 40 bar pressure as indicated in Table 6.

Feed composition has a significant effect in the process synthesis as available in literature. Feed with 72 and 50% CO₂ content has already been discussed by Maqsood *et al.* (2014). In this study, process synthesis of a feed containing moderate concentration of CO₂ (30%) and high heavy hydrocarbons (about 20%) has been presented. Different configurations of cryogenic distillation networks at different pressures have been investigated. The addition of single stage separator split the feed into methane rich and heavy hydrocarbon rich streams. This leads to lower flow rates in the columns and consequently reduction in energy. It was also found that higher pressures lead to low energy and lower purity of methane. Decrease in the column pressure increases the purity of final product but energy requirements increase.

CONCLUSION

The feed with moderate content of carbon dioxide (30%) and high heavy hydrocarbon (about 20%) was purified using different configurations of cryogenic distillation networks at different pressures. It was found that higher operating pressures lead to reduction of energy requirements but operating problems in the distillation column can arise because of the thermodynamic behavior of methane-carbon dioxide system. Final purity of methane was also found higher at lower pressures but additive requirement was also increased at 40 bar to avoid CO₂ solidification in the distillation columns. Decreasing the the pressure in the distillation column increases final purity of methane but energy requirement also increases. The addition of single stage separator for the initial removal of higher hydrocarbons and carbon dioxide reduces the energy requirement of the overall system by lowering the feed flow rate in the cryogenic distillation columns. Cryogenic distillation at lower concentration of carbon dioxide is possible at lower pressure ranges because of the phase behavior of the mixture.

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