Economic Evaluation of CO₂ Liquefaction Processes for Ship-based Carbon Capture and Storage (CCS) Chain

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ABSTRACT

This study evaluated process options for CO₂ liquefaction for ship-based Carbon Capture and Storage (CCS) and determined the optimal process. Two types of liquefaction processes, an open cycle and a closed cycle, were suggested. CO₂ is compressed and expanded as the refrigerant in open cycle, while closed cycle utilizes external refrigerants to liquefy CO₂. Design variables, such as pressure and temperature, were optimized for each liquefaction process. Life Cycle Cost (LCC) analysis was utilized for the evaluation of the candidate processes. CAPEX (Capital Expenditure) and OPEX (Operational Expenditure) were taken into account in the LCC.

KEY WORDS: Carbon Capture and Storage (CCS); CO₂ liquefaction; Process optimization; Life Cycle Cost (LCC).

INTRODUCTION

According to United National, climate change caused by the greenhouse effect is a global issue. If we do not take action, global temperature will increase by approximately 6 degrees C. Potential solutions include improvements in energy efficiency and increases in the use of renewable energy and nuclear power. Improvements in energy efficiency and the use of renewable energy do not appear to be sufficient to meet increasing energy demand, and there are safety concerns related to the use of nuclear power. Carbon capture and storage (CCS) is considered to be the practical way to mitigate the emission of CO₂, while allowing fossil fuels to still meet increasing global energy demand.

CCS involves capturing, transporting and storing CO₂ underground. First, CO₂ is captured at the emission source, such as a fossil fuel power plant or a steel mill, and then it is isolated in the onshore or offshore storage site. When an offshore storage site is selected for sequestration, the captured CO₂ can be transported by offshore pipeline or ship. In ship transportation, CO₂ should be liquefied for economic transportation, similar to the approach used for liquefied natural gas (LNG). Liquefied CO₂ occupies approximately one five hundredths of the volume of gaseous CO₂.

One of the liquefaction points should be selected for liquefaction because CO₂ can be liquefied under various conditions (pressure and temperature) between the triple point and the critical point. The conditions near the critical point are low pressure and low temperature, whereas the conditions near the critical point are high pressure and high temperature. Liquefying CO₂ near the triple point requires a high refrigeration load because of its lower temperature, while a massive compression system is necessary near the critical point due to the higher pressure that must be achieved.

After determining the optimal liquefaction point, a liquefaction process should be chosen because there are several potential processes that can be used to liquefy CO₂. The liquefaction process should be carefully selected because it is the most crucial part of the ship-based CCS chain. The cost of the liquefaction process accounts for approximately 43 % of the total cost (Aspelund, 2006). In previous studies, several CO₂ liquefaction processes were suggested and then assessed based on efficiency and cost. Aspeulund (2006) insisted that liquefaction of CO₂ in open cycle is best for large scale and suggested three liquefaction processes for different condensation pressures: 20 bar (-15 °C), 55 bar (15 °C), and 95 bar (15 °C). Decarre (2010) assumed that supercritical phase CO₂ transported by pipeline will be liquefied so the inlet pressure of CO₂ for liquefaction was higher than 100 bar and proposed a liquefaction process that utilized two cooling loops and a re-liquefaction system. ZEP (2011) assumed the inlet pressure and temperature were 100 bar and 20 °C, respectively, and proposed a simple liquefaction process that liquefied CO₂ by expansion. Alabulkarem (2012) proposed several pressurization methods, such as compression or liquefaction, and pumping by open cycle or closed cycle. He optimized liquefaction parameters for minimum overall power consumption and concluded that the liquefaction process using NH₃ consumed less power than the conventional compression cycle and open cycle.

The purpose of this study is to describe several liquefaction processes...