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Research Paper

Transient natural gas liquefaction process comparison-dynamic heat exchanger under transient changes in flow

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HIGHLIGHTS

- Two transient natural gas liquefaction processes were developed.
- Robust Model-predictive control (MPC) was designed for heat exchangers.
- Transient responses for both designs were compared.
- Natural gas consumption and liquefied natural gas production's graphs were given.

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ABSTRACT

This paper discusses transient Aspen HYSYS modeling and optimization of two natural gas liquefaction processes and identifies the rate-limiting components during load variations. The optimized model for both processes provides details for comparison. Flowrate variations included in this investigation drive transient responses of all units, especially compressors and heat exchangers. Heat exchangers commonly represent the most sensitive components to transients. This sensitivity decreases when using patent-pending dynamic heat exchanger designs and control methods. Model-predictive controls (MPC) effectively manage such heat exchangers and compare favorably with results using traditional controls. Transient efficiency graphs for both designs illustrate improvements during model predictive control. These new controls and designs optimize natural gas (NG) consumption and liquefied natural gas (LNG) production.

1. Introduction

Recently promulgated EPA regulations under Clean Air Act Sections 111(b) and 111(d) aggressively limit CO_2 emissions from the US power industry [1]. Under these regulations, new natural-gas- and coal-fired power plants can emit up to 500 and 635 kg of CO_2 per MW h. CO_2 emissions reductions from existing plants require about a 32% overall reduction from 2005 levels, although the regulation is not written in this way. The standard requires states or groups of states to meet specified total emission targets or, as an alternative, to meet emission rate targets. Current combined-cycle natural gas plants meet the standards for new power plants as they are about 50% below the emissions of most coal plants. Nevertheless, the regulation has specific provisions for limiting the amount of natural gas used to meet the new standards for existing power plants. Such large reductions from coal plants lie well beyond the reach of plant efficiency improvements or other modest operational changes and threaten decommissioning of existing plants and curtailing plans for new plants. In fact, coal consumption has declined in the US and in parts of Europe for several years and there are very few new coal plants planned.

The recent declines in coal consumption in the US largely result from low-cost natural gas competition and not from CO_2 emissions controls. Globally, fossil fuels in general and coal in particular are the most rapidly increasing primary energy sources [2]. Projected future energy sources show coal and other fossil fuels will continue to play major roles in power generation in the US and globally [3]. Power generation accounts for about one-third of the total CO_2 emissions in the US and globally [4,5]. Global CO_2 emissions must decrease by 52–70% from 2012 levels by 2050 to limit global climate change to a 2 °C increase [6]. This required reduction in total CO_2 emissions represents about twice as much CO_2 as that emitted from all forms of power generation in 2012, even without including

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future increases emissions. Therefore, global climate change mitigation requires eliminating about twice as much CO_2 as all current emissions from power generation. Emissions from power generation are large, stationary, and generally continuous sources and should be far less expensive to curtail than mobile sources or distributed, intermittent, small sources such as retail and residences. Successful climate-change mitigation critically depends on finding ways to reduce CO_2 emissions from fossil power plants. No national or global climate change policy can likely succeed without developing and deploying some kind of carbon capture technology.

Climate change mitigation also depends on increased deployment of renewable energy, especially wind and solar. Renewable energy has many redeeming virtues, but its intermittency is a major barrier to effective and reliable contributions to the grid. Arguably, the greatest technical need to increased effectiveness of renewable energy is affordable, efficient, utility-scale, rapidly responding energy storage. Energy-storing Cryogenic Carbon Capture™ (CCC) is a potential solution to both the carbon capture and the energy storage challenges in climate change mitigation.

Various methods of commercial-scale CO_2 capture promise to improve the environmental-friendliness of coal-fired power production [7–9]. Cryogenic Carbon Capture™ (CCC) is a post-combustion, retrofit or greenfield technology [10] that reduces carbon emissions from fossil-fueled power plants by 95–99% at half the cost and energy demand of current state-of-the-art carbon capture processes while providing efficient, rapidly responding, grid-scale energy storage [11,12] (Fig. 1). In addition, CCC removes other pollutants, such as SO_x, NO_x, PM_{xx} and mercury. CCC desublimates CO_2 and condenses or desublimates other pollutants, removing all species less volatile than CO. Capture efficiency increases as temperature decreases. At low enough temperatures, the exhaust exiting the stack could contain less CO_2 than the ambient air [12,13]. The external cooling loop configuration (CCC ECL) also provides significant energy storage and is the focus of this paper (see Table 1).

CCC ECL consists of two major subsystems: cryogenic carbon capture [12], and energy storage via natural gas liquefaction [14]. Natural gas liquefaction provides refrigerant for the CCC process [14].

The CCC process (1) dries and cools flue gas,(2) further cools the flue gas in a heat recovery heat exchanger to nominally −107 °C, (3) condenses contaminants such as mercury, SO_2, NO_2, Hg, and HCl at various stages during cooling (cooling happens in stages even though it is illustrated in a single step), (4) separates the solid CO_2 that forms during cooling from the remaining gas, (5) pressurizes the solid CO_2 to 70–80 bar, (6) reheats the CO_2 and the remaining flue gas to near ambient conditions (15–20 °C) by cooling the incoming gases, and (7) compresses the pressurized and now melted CO_2 stream to final delivery pressure (nominally 150 bar). Most of these steps involve traditional industrial processes; however, cooling the gas efficiently while de-sublimating CO_2 required innovation of new, patented desublimating heat exchangers [15,16]. Fig. 2 illustrates the major process steps without the energy storage component.

Table 1
Common pollutant removal temperatures.

Temperature (°C)	What is captured
−48	100% of the mercury in coal
−77	All of the above, plus 99% of the mercury from the atmosphere
−117	All of the above, plus 90% of the CO_2 from coal; SO_2 EPA standard met
−132	All of the above, plus 99% of the CO_2 from coal
−143	All of the above, plus 100% of the CO_2 from coal. Below this point, the exhaust exiting the stack is cleaner than the surrounding air
−150	All of the above, plus 80% of the CO_2 from the atmosphere
−162	All of the above, plus 99.5% of the CO_2 from the atmosphere

The CCC process operates with the same amount of refrigerant generation and use in normal operation or balanced mode. The energy-storing (ES) mode of the process generates more refrigerant than the carbon capture process uses and stores the excess refrigerant in an insulated vessel as a liquid at the low-temperature, modest-pressure point in the cycle. This normally occurs during off-peak hours or when excess power from wind farms or other intermittent sources enters the grid. During peak demand, the stored, condensed refrigerant provides energy recovery (ER) by reducing the compressor load, decreasing the energy required to operate the cryogenic carbon capture and delivering the saved parasitic load to the grid for as long as the stored refrigerant lasts. The amount of refrigerant required by CCC for 3–4 h of utility-scale power plants requires only a fraction of the capacity of commercially available LNG storage tanks.

Fig. 3 illustrates the overall energy storing process. The straight line is the constant energy stream needed to capture CO_2 from a plant operating at constant load. The net plant output meets the varying demand, as indicated by the red line. The yellow line represents the NG flow into the plant. The difference between the yellow line and the average demand would be the net NG outflow either into a simple cycle turbine or the NG pipeline. This investigation focuses on the LNG generation process during the transients in NG flow.

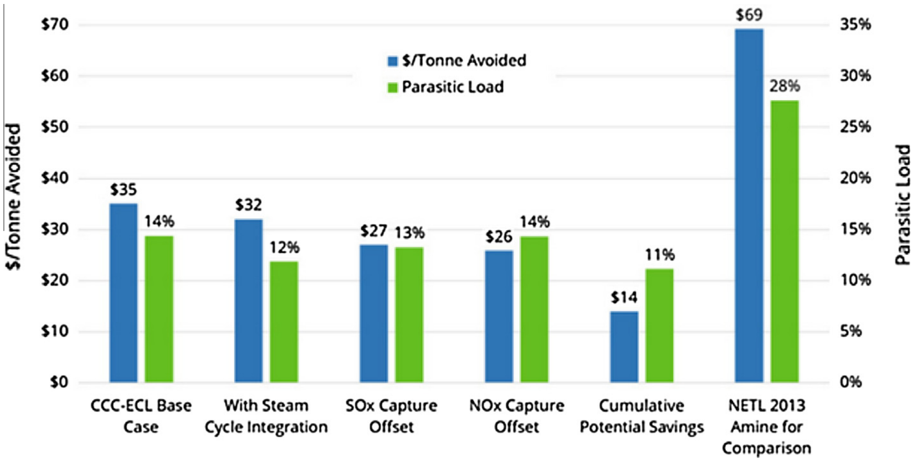

Fig. 1. Projected forts year costs and parasitic of CCC with various integration in a greenfield installation [11].