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Development of a simulation package of natural gas liquefaction system

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Abstract

Gas liquefaction employs refrigeration process to bring feed gas temperature down to enable it to condense. The refrigeration system for natural gas liquefaction consists of some components combined in several configurations. One of those systems is the reversed-Brayton and its modified cycles.A numerical program package was developed to model and analyze the process of small scale natural gas liquefaction with maximum flowrate 1 MTPA or 31.7 kg/s. The package was set for the simple 1-stage reversed Brayton cycle and its modified cycle. The process was modelled with assumptions of a steady state condition and natural gas that made of 100% methane. Parameters and variables that may be involved in the simulation are the feed gas flow rate, temperature and pressure, the selection of refrigerants for the cycle, the refrigeration working pressures. The package enable one to calculate the amount of work required for liquefaction process as well as the system's performance in term of its figure of merit.

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1. Introduction

Natural gas is a superior energy source in environmental view. Natural gas can reduce carbondioxide (CO_2) emission by 20%, sulphur oxide (SO_x) up to 100%, nitrogen oxide (NO_x) up to 90%, and other particulate up to 99% [1]. In general, natural gas is distributed in liquid form. This is to make the transportation more convenience, since the volume of liquified natural gas is 600 times lower than in its gas form.

Indonesia has huge potential in small-scale natural gas fields such as Ombilih, West Sumatera. The natural gases are non-conventional gas originated from chemical and physical manipulation of coal (coal bed methane). According to Amirullah, et. al [2], natural gas made of 91,81% mole methane are obtained two days after the drill in Ombilih field. Liquefaction system with capacity up to 1 MTPA (31,71 kg/s) is needed to utilize such small-scale gas fields. Chang, et. al [3] has researched about the usage of simple 1-stage reversed-Brayton cycle and its modified cycle to liquefy methane gas with nitrogen as refrigerant. Chang also reviewed some cryogenic refrigeration cycles for liquefaction system thermodinamically [4]. In this paper, a simulator is designed to analyze the process of natural gas liquefaction with simple 1-stage reversed-Brayton cycle and its modified cycle.

2. The object of the study

2.1. Refrigeration cycle for natural gas liquefaction

Refrigeration cycle for natural gas liquefaction has different structure than liquefaction cycle for air. This system consist of closed cycle with temperature difference between feed gas and liquefied natural gas as the cooling load. As Chang stated [3], the

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performance of refrigeration cycle for liquefaction can be determined from its *figure of merit* (FOM). FOM of a system is defined as the ratio of minimum work required and actual work done for the liquefaction process as stated in equation (1).

$$\mathrm{FOM} = \frac{\dot{W}_{min}}{\dot{W}_C - \dot{W}_E} = \frac{\dot{m}_{NG}(h_L - h_0) - T_0(s_L - s_0)}{\dot{W}_C - \dot{W}_E} \tag{1}$$

Irreversibility is a difference between actual work done and minimum work required, and it is equal with exergy lost in the system. Exergy indicate the potential of energy that can be used for work. Exergy is defined as multiplication ambient temperature with entropy generation rate in the system. Equation (2) stated the amount of exergy lost in a refrigeration cycle for liquefaction.

$$(\dot{W}_C - \dot{W}_E) - \dot{W}_{min} = T_0 \times \dot{S}_{gen} \tag{2}$$

2.1.1. Reversed-Brayton cycle

Reversed-brayton cycle and its modified cycle are some cycles that can be used for natural gas liquefaction. The cycles are shown in **Fig. 1**. Modification of reversed-Brayton cycle is conducted by Chang [3] to reduce the entropy generation rate in *liquefying heat exchanger* (LHX) due to large temperature difference between natural gas and refrigerant. However, the modification has consequence of increasing entropy generation rate in *recuperative heat exchanger* (RHX) instead.

2.2. System components

A liquefaction system consists of several components. Some of the fundamental components are heat exchanger, compressor, aftercooler, and expansion unit such as expander or throttle.

2.2.1. Compressor

Compressor applied in the small-scale natural gas liquefaction system usually is a reciprocating type with pressure ratio no more than three [5]. Reciprocating compressor work for low up to medium mass flow rate at high pressure [6]. There are two ways to detemine the compression work, isentropic and polytropic approach. In isentropic approach, entropy of the fluid is ideally constant before and after compression process. Polytropic approach use ideal gas equation to determine the efficiency. Polytropic efficiency is used in this paper and shown in equation (3), while the compression work is shown in equation (4).

$$\eta_{p,C} = \frac{\left(\frac{\gamma_C - 1}{\gamma_C}\right) x \ln\left(\frac{P_{C,out}}{P_{C,in}}\right)}{\ln\left(\frac{T_{C,out}}{T_{C,,in}}\right)} \tag{3}$$

$$\dot{W}_{comp} = \dot{m}_{Refr}(h_{C,out} - h_{C,in}) \tag{4}$$

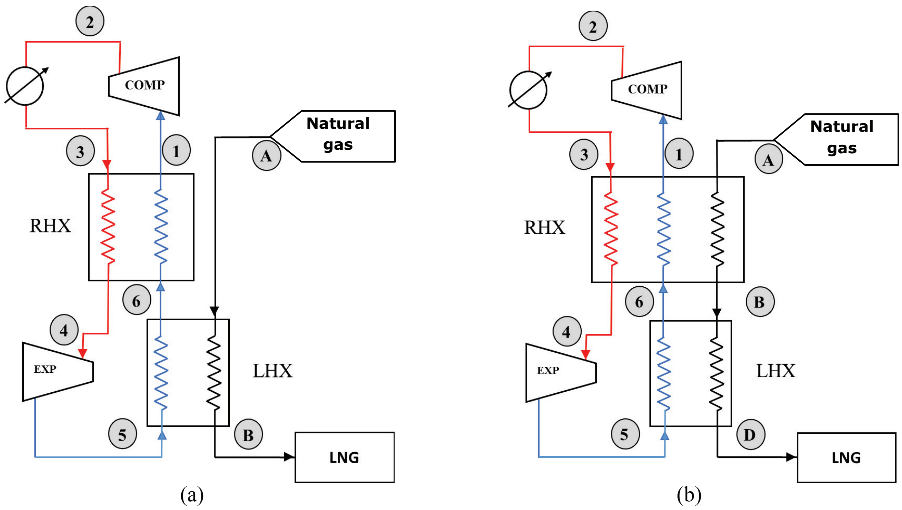

Fig.1. Schematic of 1-stage *reversed*-Brayton cycle (a) simple (b) modified.