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Global cost optimization of a mini-scale liquefied natural gas plant

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ABSTRACT

Cryogenic natural gas liquefaction plant has huge capital and operating expenses corresponding to operating equipment and energy utilization. Considering ever-increasing energy price, therefore, minimization of energy consumption rate for a better profit is highly required. However, any un-engineered energy cut off would result in larger surface area of heat-exchanger and hence bigger capital cost. Here, the net profit of establishing a mini 50 ton/day liquefied natural gas facility, operating for 25 years, is optimized via Genetic Algorithm technique. Poly Refrigerant Integrated Cycle Operations (PRICO) process is simulated in HYSYS environment and linked to MATLAB software for subsequent maximization. The simulation resulted in total consumed power, heat exchanger area and total profit by 2745.33 kW, 3285.58 m^2 and 1266.64 million$, respectively. In order to determine unit efficiency and plant irreversibility rate, exergy analysis is performed on individual equipment. Basically, thirteen independent variables are considered for optimization of objective function. Sensitivity analysis for objective function is considered by altering each variable. Final results indicate 9.26% rise in total profit (1383.95 million$) by 59% reduction in energy utilization (1127.68 kW) and 37.50% in heat-exchanger size (2053.7 m^2). Meanwhile, the total and heat-exchanger exergy losses are decreased by 65.8% and 80.7%, respectively.

1. Introduction

In recent years, natural gas utilization for residential appliances has also expanded to industries since it is the most environmentally benign fossil fuel. Its market is growing steadily and 4.5% growth (p.a.) is projected for global LNG (Liquefied Natural Gas) supply until 2030, which is twice of total global gas production (2.1% p.a.) and faster than inter-regional pipeline trade (3.0% p.a.) [1]. Here, mini LNG facilities can secure natural gas supply to areas with low demand and also cover peak shaving in more intense market regions than pipeline. LNG merit against natural gas (NG) would be in its storage capacity (1/600th of the original volume) at near atmospheric pressure [2].

Although mass quantity production of LNG is more economical, there are challenges that entail establishing small plants. Lower total cost (sum of capital and operational expenses), fewer equipment as well as facility of installation, maintenance and operation in mini processes would be advantageous to base load projects which normally require several years of engineering, procurement, construction and commissioning. Hence, construction of mini plants can speed to market delivery compare to larger scale infrastructures [3].

Single Mixed Refrigerant (SMR) technology is extensively used in LNG plants since it has high efficiency, small pieces of rotating equipment and flexibility for altering feed gas as well as operating environment conditions [3]. Minimization of operating costs and equipment sizes has extensively practiced for SMRs to enhance final unit profit. Mokarizadeh and Mowla [4] optimized a two-compression stage process with GA method which improved the compressors' energy consumption by 3% and 6.5% per kg of LNG when compared to Lee's work [5]. Mehrpooya et al. [6] achieved a 28% rise in profit by optimization of NGL recovery unit. Aspelund et al. [7] used Tabu Search (TS) and the Nelder-Mead Downhill Simplex (NMDS) method to find the total refrigerant flow rate, composition and the refrigerant suction and condenser pressures

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Nomenclature

B	Exergy, $kJ/kgmol$
g_E	Gravitational acceleration, m^2/s
Q_i°	Heat Transfer Rate, kJ/hr
W°	Shaft Work, kJ/hr
Z	Altitude of the stream above sea level, m
V	Velocity, m/s
T	Temperature, °C
P	Pressure, kPa
h	Enthalpy, $kJ/kgmol$
s	Entropy, $kJ/kgmol$
I	Exergy loss, kJ/hr
L	LNG sale price, $
d	Yearly rise of LNG price, %
CB	Free on board purchase cost, $
Pc	Energy consumption of compressor, hp
$m$$	Million dollars
A	Heat transfer area, m^2
m	Total energy consumed (kW)
n	Electricity price ($/$kWh$)
u	Rate of increase in electricity price, %
F	Mass flow rate, kg/s
X	Design variable
Y	Objective function
Pe	Penalty function
Greek letters	
$\sum$	Sum
ε	Scientific exergy efficiency
Superscripts	
$p.a.$	Per annum
id	Ideal state
ST	Standard
N	Number of components in material stream
Abbreviation	
GA	Genetic algorithm
NG	Natural gas
NGL	Natural gas liquids
MHEX	Main heat exchanger
SMR	Single mixed refrigerant
LPR	Low pressure refrigerant
atm	Atmosphere
VLV	Valve
Subscripts	
C	Cold
H	Hot
in	Input material or energy stream
out	Output or energy stream
Ph	Physical
$Chem$	Chemical
$Kinetic$	Kinetic component of exergy
$Potentioal$	Potential component of exergy
$\circ$	Reference condition
rel	Relative to the surface of the earth
i	ith component

that minimize the energy requirements of a PRICO process. Wahl et al. [8] proposed a constraint handling method for PRICO process by utilizing process characteristics and compared with static penalty function formulations. Considering plant's total energy consumption as objective function, Alabdulkarem et al. [9] optimized a C3MR process with 22 independent variables via genetic algorithm. For more convenience, firstly the MCR section and subsequently the propane cycle was optimized which reduced energy consumption in each section by 13.28% and 17.16, respectively. Nogal et al. [10] performed a review on LNG cascade technologies and enhanced the sum of total cost and energy consumption via GA. Quite recently, Hwang and Lee [11] considered elaborate offshore selection criteria including connectivity costs, deck area construction expenses plus Main Cryogenic Heat Exchanger (MCHE) and separators' distance from the centerline of hull to identify an optimal liquefaction process system. Also, Pham et al. [12] exploited process knowledge inspired decision-making method for liquefied natural gas process optimization. Energy saving of 30.6% can be accomplished by the optimization. Ding et al. [13] simulated, analyzed and optimized mixed fluid cascade process by genetic algorithm. Song et al. [14] modeled a single nitrogen expansion process with carbon dioxide pre-cooling in Aspen HYSYS, which is connected to MATLAB by ActiveX technology to establish a hybrid simulation platform. Qyyum et al. [15] modeled a SMR process in Aspen Hysys then connected to a Microsoft Visual Studio environment and optimized SMR process by proposing hybrid modified coordinate descent (HMCD) algorithm. A modified DIRECT (DIviding a hyper-RECTangle) algorithm with a sub-dividing step for considering hidden constraints is proposed by Na et al. [16] which by applying proposed algorithm the specific power required for natural gas liquefaction decreased to 18.9%. Lee et al. [17] proposed a process design of Organic Rankine Cycle using Aspen Plus with a stochastic solver, GA, and an Aspen Plus-MATLAB interface.

According to the results of previous works, it can be concluded that mixed refrigerant technology is a suitable option from energy consumption aspect. Among the large variety of mixed refrigerant processes, PRICO process is the best choice for a mini-scale LNG plant due to its simplicity and therefore, it is considered as baseline process for this study. Moreover, performance analysis and cost optimization have not been performed on a mini-scale LNG plant in the recent studies. Thus, in this paper, an analysis and optimization of a liquefied natural gas plant were carried out through genetic algorithm. Since the objective function is total profit, there would be a tradeoff between consumed electricity charges and total heat exchanger surface area. Although minimizing compressor power might substantially increase heat transfer surface area for MHEX. Hence, the objective function is considered to cover both aspects (capital and operation costs).

2. Objective

As the benefits of single-mixed refrigerant processes and developing small-scale LNG units were considered earlier, here the profit of a mini 50 tons a day PRICO®SMR LNG plant is maximized for 25 years full operation lifetime. The process is simulated in HYSYS environment and subsequently linked to MATLAB software for determining optimized energy consumption, main heat exchanger (MHEX) surface area and LNG sales profit by using Genetic Algorithm sub-function.