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Applying an integrated trigeneration incorporating hybrid energy systems for natural gas liquefaction

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ABSTRACT

Utilizing absorption refrigeration system as an alternative to compression refrigeration system of MFC refrigeration cycle in an integrated super structure with the main aim of reduction in required energy is investigated. High energy consumption in these units is reduced because of the removal of a stage of the compression system, while the possibility of using waste energy through the use of absorption cooling can be provided. A superstructure is composed of following items: combined cooling, heating and power (CCHP), molten carbonate fuel cell (MCFC), gas turbine, water-ammonia absorption refrigeration system as well as two mixed refrigerant refrigeration cycle for producing the required cooling and Heat recovery steam generator (HRSG) for power generation and thermal recovery. Exergy analysis shows that the highest exergy destruction is imposed by after-burner with the amount of 33.91% and the lowest exergy destruction is occurred in the valves by the amount of 0.83%. The presented integrated structure has overall thermal efficiency (LHV Base) of 70.56%, and the Specific power of 0.162 kWh/kg LNG. Sensitivity analysis of the integrated system is carried out through changing the amount of fuel utilization coefficient, oxidant mass flow rate, mass flow rates of methane and nitrogen in the natural gas. The differences in the amount of consumed power and generated power in the integrated structure can be minimized by increasing the pressure ratio in gas turbines, and the mass flow rate of LNG production can be maximized to 6778.93 kg/h.

1. Introduction

Improving the energy efficiency of the liquefaction processes can be the most important issue in LNG plants [1]. LNG technologies consume the high amount of energy to liquefy and sub-cool the natural gas to temperatures under −160 °C [2]. The compression refrigeration cycles consume most of the aforementioned energy [3]. Specific power consumption, which is a parameter of efficiency, can be defined to illustrate the amount of the required power to yield 1 kg of LNG [4]. Approximately 60% of the cost is related to the onshore and main part of it can be the refinery of LNG, and LNG unit costs approximately is 30% of onshore cost [5]. This indicates that type of liquefaction processes play an important role in LNG production projects. The most important problem for dealing with LNG production technologies is their high energy consumption. The major portion is related to turbine, and operation of refrigeration cycles compressors [6]. The liquefaction processes can dramatically improve the energy efficiency of LNG to increase efficiency and reduce the fuel consumption and carbon emissions [7]. In the refrigeration cycles used LNG processes, for the refrigerant cooling by environmental air or water to the desired temperature, the high-pressure compressors with very high energy consumption are used. It can be said that the most important way to reduce LNG production costs and increase the cost of this energy carrier is suitable approaches to reduce the amount of consumed energy [8].

There have been several configurations for liquefying natural gas. One way to increase the efficiency of the process is to use the wasted thermal energy. Wasted energy from different sources such as hot gases resulting from combustion (in the turbines, furnaces and reboiler), can provide requirement of the process. Among these equipment, gas turbine, supplying required energy for compressors in LNG unit, is a valuable waste energy source (high heat value) that can be used in absorption refrigeration systems [9]. In addition, some studies have been conducted on the exergy analysis in the

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Nomenclature

E	Specific flow exergy kJ/(kgmole)
Ex	Exergy (kW)
m	Mass flow rate (kgmole/h)
H	Enthalpy (kJ/kgmole)
P	Pressure (kPa)
T	Temperature (°C)
LHV	Lower heating value of fuel (kJ/kgmole)
HHV	Higher heating value of fuel (kJ/kgmole)
W	Work (kW)
S	Entropy (kJ/(kgmole.°C))
V	Cell operating output voltage (V)
I	Current density(A/(cm^2))
P_i	partial pressure of species i, (bar)
n_i	moles rate of species i, (mole/s)

Greek letters

η	Efficiency
Σ	Sum

Subscripts

An	Anode
C	Cold
H	Hot
I	Inlet
Cat	Cathode
O	Outlet
Id	Ideal
Ph	Physical
Ch	Chemical
T	Total
A	Air

Superscript

T	Thermal component
P	Pressure component

Abbreviations

APCI	Air Products and Chemicals, Inc.
C3-MR	Propane precooling
GT	Gas Turbines
CC	Composite Curve
DMR	Dual mixed refrigerant
LNG	Liquefied natural gas
MR	Mixed refrigerant
AB	Absorption Cycle
AC	Electrical power output with conversion to alternating Current
DC	Electrical power output with conversion to direct Current
HRSG	Heat Recovery Steam Generator
MFC	Mixed fluid cascade
NGL	Natural gas liquids
NG	Natural gas
NRU	Nitrogen Rejection Unit
MCFC	Molten-Carbonate Fuel Cell
ST	Stirling motor
CCHP	Combined Cooling, heating and Power

Names used for blocks in plants

Ci	Compressor
U_f	fuel utilization coefficient
Exi	Turbo expander
Ti	Tower
HXi	Multi stream heat exchanger
Di	Flash drum
Vi	Valve

number of LNG production processes and absorption refrigeration systems [10]. Thermodynamic and economic optimization has been carried out for LNG mixed refrigerant processes [11]. Thermodynamic analysis is also conducted on a hybrid energy systems including a gas turbine, an ORC cycle and an absorption refrigeration cycle proposed as a combined cooling, heating and power system [12]. As an alternative approach for improving energy return cycles of absorption cooling units, LNG can be used for cooling. Take advantage of the energy dissipation properties of absorption cooling cycles from different parts of the unit is possible in this cycle [13].

Thermodynamic approaches are used to design mixed refrigerant refrigeration system considering optimum values of operating conditions [14]. Optimal arrangement is also obtained for the mixed refrigerant refrigeration system [15]. Superstructure optimization of the olefin separation system has also obtained by harmony search and genetic algorithms [16]. LNG processes have been investigated by energy and advanced exergy and exergoeconomic analyses methods [17]. Advanced Exergoeconomic evaluation of single mixed refrigerant natural gas liquefaction processes has been carried out [18]. Additionally, advanced exergoeconomic analysis is employed for analyzing multistage mixed refrigerant systems [19].

Hybrid energy systems have attracted considerable attention in recent years [20]. Hybrid fuel cell power plants have been integrated with natural gas liquefaction processes to provide the required power and refrigeration. The exhaust heat from the fuel cell systems can be used as the required heat duty in the absorption refrigeration cycles generator. Solid oxide and molten carbonate fuel cells have been considered in such hybrid power plants [21]. A hybrid molten carbonate fuel cell-supercritical carbon dioxide brayton cycle system has been developed and analyzed [22]. Conceptual and basic process design is carried out for a novel integrated cogeneration power plant energy system [23]. An integrated SOFC system, absorption refrigeration cycle and Rankine steam cycle is introduced and analyzed [24]. A hybrid system linking a pressurized SOFC with a gas turbine Brayton cycle is analyzed considering different SOFC configurations. Results showed that electrical efficiency of the process is 62.4%. Optimal design of SOFC-GT power plants is studied [25]. Hybrid SOFC biomass fueled, steam power plant and chemical looping combustion system is investigated [26].

A novel cycle combining three technologies of solid oxide fuel cell, micro gas turbine, and organic Rankine cycle has been proposed to generate power in micro scale. The results show that in micro-scale power generation, fuel saving of about 45% is achievable and the overall efficiency can reach more than 65% [27]. A hybrid molten carbonate fuel cell system and cryogenic carbon dioxide process is analyzed by exergy cost method [28]. The reported electrical efficiency is about 60%. In another study MCFC system was integrated with hydrogen production, absorption refrigeration system and cryogenics CO_2 capturing processes [29]. The results indicated that the electrical efficiency is 58% (LHV). A hybrid SOFC and solar dish CCHP system is designed for providing