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Research Paper

# A novel energy efficient LNG/NGL recovery process using absorption and mixed refrigerant refrigeration cycles – Economic and exergy analyses

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## HIGHLIGHTS

- Employing absorption refrigeration system in lieu of precooling stage of MFC cycle.
- Performing economic sensitivity analysis with respect to products and utility prices.
- Applying thermal integration for reducing the number of equipment and specific power.

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## ABSTRACT

A novel integrated process comprising natural gas liquids recovery along with natural gas liquefaction is investigated. Processes integration and design at the same time can reduce the number of required equipment and energy consumption in the units. Utilizing absorption refrigeration system in lieu of precooling stage of mixed fluid cascade refrigeration system in an energy efficient LNG-NGL recovery process with the main aim of reduction in required energy is investigated. High amount of energy consumption in these units is reduced due to the removal of a stage of the compression system, while the possibility of using waste thermal energy can be provided using absorption refrigeration system. The results of exergy analysis illustrate that the highest amount of exergy destruction is occurred in the air coolers before and after installation of the absorption refrigeration cycle at a rate of 56.21% and 42.72%, respectively. Sensitivity analysis has been carried out for economic parameters with respect to the utilities price as well as effect of products price on the market with respect to the presented structures.



## 1. Introduction

LNG is considered as one of the most significant thermodynamic processes in low temperature application of natural gas industry [1]. It also is one of the costly processes in oil and gas industries from aspects of installation and operation costs. Energy is consumed about 250–800 kWh per ton of LNG production in most plants all around the world [2]. Fixed investment from 500 to 600 US$ per ton LNG can be needed. Production and transition cost of natural gas are divided into two parts of onshore and offshore. Approximately 60% of cost is related to the onshore and main part of it can be the refinery of LNG, and LNG unit. Approximately 30% of cost is onshore cost. 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 refrigerants as well as refrigeration cycles compressors. Numerous articles for reducing energy consumption and natural gas liquefaction are provided [3]. The articles show integrated and optimized processes as well as appropriate way to reduce energy consumption. A novel model to choice optimal combination of refrigeration systems for reducing both operating and capital costs of an LNG plant is presented [4]. A superstructure optimization of an intricate refrigeration system is also developed to optimize the key decision variables in refrigeration cycle [5]. Evaluation and optimization of a mixed fluid cascade process has been carried out [6]. An important developments in the evolution of DMR process for natural gas liquefaction along with optimization is investigated [7]. The potential of various options for improving liquefaction cycle efficiency to improve LNG plant energy efficiency is carried out [8]. A novel configuration of natural gas liquids recovery process is presented, and the configuration is compared with nine NGL

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**Nomenclature**

| | |
|---|---|
| E | specific flow exergy (kJ/kg mole) |
| Ex | exergy (kW) |
| $\dot{m}$ | mass flow rate (kg mole/s) |
| H | enthalpy (kJ/kg mole) |
| P | pressure (kPa) |
| T | temperature (°C) |
| W | work (kW) |
| S | ENTROPY (kJ/kg mole·°C) |

*Greek letters*

| | |
|---|---|
| $\eta$ | efficiency |
| $\Sigma$ | sum |
| $\int$ | integration |

*Subscripts*

| | |
|---|---|
| C | cold |
| H | hot |
| I | inlet |
| O | outlet |
| Id | ideal |
| Ph | physical |
| Ch | chemical |
| T | total |
| A | air |
| acap | annualized capital cost |
| Cap | capital cost |
| aope | annualized operating cost |
| Ope | operating cost |
| Rep | replacement cost |
| Cw | cooling water |
| arep | annualized replacement cost |
| amain | annualized maintenance cost |
| Main | maintenance cost |

*Superscript*

| | |
|---|---|
| P | pressure component |
| T | thermal component |

*Abbreviations*

| | |
|---|---|
| APCI | Air Products and Chemicals, Inc. |
| C3MR | propane precooling |
| DMR | dual mixed refrigerant |
| LNG | liquefied natural gas |
| MR | mixed refrigerant |
| AR | absorption refrigeration |
| tpa | tonnes per annum |
| GMDH | Group Method of Data Handling |
| MFC | mixed fluid cascade |
| NGL | natural gas liquids |
| NG | natural gas |
| NRU | nitrogen rejection unit |
| CC | composite curves |
| CRF | capital recovery factor |
| ACS | annualized Cost of System |
| KSMR | Korea Single Mixed Refrigerant |
| APCI | Air Products and Chemicals, Inc. |
| HP | Horsepower |
| MMBTU | Million British Thermal Units |
| NLP | non-linear programming |
| COP | cost of product |
| SQP | sequential quadratic programming |
| PSP | particle swarm paradigm |

*Names used for blocks in plants*

| | |
|---|---|
| Exi | turbo expander |
| Ti | tower |
| ACi | air cooler |
| Vi | valve |
| Ci | compressor |
| HXi | multi stream heat exchanger |
| Di | flash drum |

recovery processes for offshore applications. The results suggest that the proposed NGL configuration is the most efficient in terms of heat integration and capital cost [9]. Another novel NGL process including a self-refrigeration system used SQP for optimizing of a PRICO process is investigated [10]. Mathematical and thermodynamic synthesis is employed for design of mixed refrigerant refrigeration system in cryogenic process and optimal operating parameters have been obtained [11]. Particle swarm paradigm is employed to optimize SMR process while minimization of the requirement energy for compressing is employed as an objective function. Results show that the stochastic features of PSP are more beneficial to avoid the local optima and find the more feasible solution [12]. Thermodynamic and economic optimization of mixed refrigerant cycles including C3MR and DMR processes are done by multi-objective Pareto optimization [13].

An innovative process configuration has been introduced for producing of both NGL and LNG. The process is operated with low energy requirement [14]. Cryogenic liquid recovery processes have been analyzed and influential parameters for assessing the degree of integration in the system have been introduced [15]. Integrated liquid recovery plants has been investigated, and design parameters of aforementioned plants has been optimized using genetic algorithm [16]. Cascading of refrigeration cycle using of different mixed refrigerants and hybridization of renewable energy power cycles to refrigeration cycles are employed for hydrogen liquefaction [17]. Genetic algorithm is employed for optimizing of mixed refrigerant composition for the PRICO liquefaction process. Principles are proposed to judge the fitness of the MR composition of PRICO [18]. GMDH, also presented in [19], as novel multi-hybrid model, optimized with genetic algorithm, is hired to achieve optimal consumed power for two cascade refrigeration cycles [20]. The processes employed for natural gas liquefaction are considered as the most important and low temperature ones that need high rate of cryogenic refrigeration such as NGL recovery process configuration with an auto-refrigeration system [21]. A novel integrated and optimization schemes for NGL recovery process and liquefaction is presented [22]. The liquefaction of natural gas is done by the developed KSMR liquefaction cycle whereas the separation of natural gas liquids is achieved through energy efficient thermally coupled distillation schemes [23]. Exergoeconomic and sensitivity analyses are carried out to recognize variables affecting liquefaction cost. The total installed cost of the plant equipment is about 1.9 US$ bil-