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Techno-economic evaluation for the heat integration of vaporisation cold energy in natural gas processing

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HIGHLIGHTS

- Development of thermal integration modelling framework for the utilisation of LNG cold energy.
- Feasibility study for various design options for the integration of low-temperature cold energy.
- Provision of a design approach for achieving efficient use of cold energy in LNG terminals.
- Understanding of techno-economic impacts associated with the thermal integration of LNG cold energy.

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ABSTRACT

This paper addresses a conceptual study investigating the techno-economic feasibility for the thermal Integration of LNG cold vaporisation energy in power generation applications. In conventional regasification systems, this valuable LNG cold energy is often being wasted to ambient heat sources, representing a thermodynamic inefficient process with a significant thermal impact on the local environment. A combined facility consisting of a non-integrated Combined Cycle Power Plant (CCPP) and an LNG receiving terminal employing traditional Open Rack Vaporisers (ORV) technology, has been modelled, as a base case. Retrofit strategies for the integration of LNG cold energy have been investigated, and their impacts on power production and system efficiency are systematically compared. Retrofit design options considered in this work include the use of a propane Rankine cycle coupled with the direct expansion of natural gas, the integration of a closed-loop water cycle or open-loop water circuit with a steam Rankine cycle, and the facilitation of integrated air cooling for a gas turbine.

1. Introduction

The utilisation of NG (natural gas) as a source of cleaner energy has seen significant worldwide growth over the last decade. With rising global energy demand and the need for environmentally cleaner technologies, countries are keen to establish a reliable and energy efficient means of addressing these challenges. With continuous development in technology and infrastructure in the LNG (liquefied natural gas) value chain, the LNG global energy market share has also continued to see a tremendous growth across the years.

The liquefaction process provides greater trade flexibility and an alternative means of distributing NG that overcomes the economic barriers imposed where NG is needed at large distances from the source. However, the liquefaction operation is also an extremely energy and cost intensive process as it utilises cryogenic refrigeration technologies to convert the NG to its liquid phase. The transported LNG therefore possesses a huge amount of cold energy that could potentially be recovered in downstream operations when it is re-gasified to NG.

For the typical heating curve of LNG, the cryogenic energy released during vaporisation to NG could provide an energy saving of 200 kW h/ton LNG [1]. However, LNG receiving terminals employing conventional vaporisation technologies often fail to recover this valuable low temperature cold energy. These conventional processes are thermally inefficient and have a negative sustainable impact on the locality as ambient heat sources are used to vaporise the processed LNG.

Therefore, this paper aims to conceptually identify and enhance the understanding of the potential options available for the recovery of potential LNG cold energy. Specific focus into validating the integrated design for utilising LNG cold energy in the power generation industry will be considered. The current study shall aim to conceptually study the potential options available for Process Integration, investigating the improvement in thermo-economic performance

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Nomenclature

U	overall heat transfer coefficient (kJ/m^2 K h)
ΔT_{MIN}	minimum temperature difference

Abbreviation

AAV	ambient air vaporisers
AOB	annual operational benefit
AOC	annual operating cost
ASL	air separation and liquefaction
BCRT	base case receiving terminal
BOG	boil off gas
BSRC	bottoming steam Rankine cycle
CCPC	cryogenic combined power cycle
CCPP	combined cycle power plant
CIPC	combined integrated power cycle
CLWC	closed loop water cycle
CWU	cooling water utility
DE	direct expansion
EUS	external utility systems
GT	gas turbine
GT-IAC	gas turbine integrated air chilling
HEX	heat exchanger
HR	heat rate
HRSG	heat recovery steam generator
LHV	low heating value
LNG	liquefied natural gas
MR	mixed refrigerant
NG	natural gas
N.I.A	non integrated scheme A
N.I.B	non integrated scheme B
NPO	net power output
OLWC	open loop water cycle
ORV	open rack vaporisers
PRC	propane rankine cycle
RC	rankine cycle
RH	relative humidity
SCV	submerged combustion vaporisers
SRC	steam Rankine cycle
SW	sea water
TIT	turbine inlet temperature
UC	utility consumption

to be realised through implementing these design schemes. Key operating parameters that affect the performance of the discussed options shall also be identified in the sensitivity analysis.

A base case facility consisting of a non-integrated LNG receiving terminal and a Combined Cycle Power Plant (CCPP) provides a reference performance for the potential integration schemes to be analysed in this study. Operating concerns associated with conventional LNG gasification technology, and the effects of varying climatic conditions on the CCPP performance are identified by carrying out a thermo-economic analysis of the base case facility.

The option to further improve the thermo-economic performance of this combined facility through the integration of LNG cold energy is studied in details in this paper. Thermal recovery of LNG cold energy in the gasification process through implementation of a Combined Cryogenic Power Cycle (CCPC) scheme is a design option that shall be initially analysed for non-integrated retrofit scenarios. Improving energy efficiency of the base case facility shall then be addressed by thermal integration of the LNG vaporisation process, with the CCPP steam condensing process in the Open Loop Water Cycle (OLWC) scheme. A final integrated scheme that can overcome the effects of increasing ambient temperature during the operation of CCPP shall also be analysed in the Gas Turbine Integrated Air cooling (GT-IAC) Scheme.

2. Literature review

2.1. LNG re-gasification

The LNG re-gasification process is the key thermal operation employed in receiving terminals and is used to convert the cryogenic liquid back to NG for suitable pipeline distribution. The two most commonly employed LNG vaporisation technologies are the Open Rack Vaporisers (ORV) and Submerged Combustion Vaporisers (SCV) [2]:

- *Open Rack Vaporisers (ORV):* Heat exchange occurs between a falling film of ambient seawater (heat source) and LNG in an open rack finned panel type arrangement. Ambient seawater temperature is typically required above 5 °C to avoid freezing during vaporisation [3]. Large LNG throughputs during re-gasification will require higher power consumption to provide the shaftpower needed in pumping the seawater, thus the major operating costs usually associated with the ORV system result from the pumping and treatment operations. The major concern is the thermal impacts of seawater discharge on the quality of water and marine life.
- *Submerged Combustion Vaporisers (SCV):* LNG flows through stainless steel tubes submerged in a water bath and is vaporised by heating the water using a combustion burner. The combustion process utilises low pressure NG from the send out system or BOG (Boil Off Gas) system to heat the water using hot flue gases. The main advantage of SCV is the greater operational flexibility in maintaining stable operation during start- up/ shut- down and load fluctuations due to the high thermal capacity of the bath [3]. A typical analysis shows that for an SCV facility of 1 BCFD NG send out, approximately 600 MMbtu/h of fuel gas is required to vaporise LNG [4].

A significant amount of cryogenic energy (850 kW h/ton-LNG) is utilised in the liquefaction of NG before transportation. The total amount of LNG cold energy essentially wasted is about 20 million MW h/y [1]. The followings are some of options for LNG cold energy integration currently being utilised in industry:

- *Cryogenic Air Separation and Liquefaction (ASL):* Integration of LNG cold energy can be used to assist the cryogenic requirements of the ASL process by providing a low temperature heat sink that can be used to aid refrigerant (N_2) condensation.
- *CO_2 solidification and liquefaction:* The integration of LNG cold energy has been utilised to achieve liquefaction of CO_2 by indirect coupling with an intermediate cycle fluid. Solidification of CO_2 to produce dry ice at atmospheric conditions is another process where the low temperature cold energy of LNG could be effectively utilised [5–7].
- *BOG re-liquefaction:* Part of the cold energy required to achieve the condensation of BOG can be provided from sub-cooled LNG in the initial pumping stages during the send-out operation [8].