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PERFORMANCE ENHANCEMENT OF OFFSHORE LNG PROCESSES BY INTRODUCING OPTIMAL MIXED REFRIGERANT SELF-COOLING RECUPERATOR

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ABSTRACT

Liquefaction is recognized as one of the economical and feasible strategies for storing and transporting natural gas (NG). Among several NG liquefaction processes, the single mixed refrigerant (SMR) process are considered most suitable for offshore liquefied NG (LNG) production, mainly due to simple and compact design. However, these processes consume a tremendous amount of energy that leads to high operating costs. Therefore, process engineers and researchers associated with FLNG-FPSO industry are still trying to enhance the performance of the offshore LNG processes. Within this context, this study presents an innovative enhancement in SMR liquefaction process by introducing high-boiling mixed refrigerant self-recuperator. The proposed self-recuperative SMR process is further enhanced by replacing Joule-Thomson (JT) valve with cryogenic liquid turbine, which ultimately reduces the overall process entropy generation. The proposed process gives LNG product with ≥94.0% liquefaction rate on the expense 4.98 kW/kmol-NG that is 19% and 25% lower than that of JT valve based self-recuperative SMR process and convention SMR process, respectively. The proposed enhancement can also be employed to other energy intensive refrigerant and liquefaction processes in order to improve an overall process efficiency.

Keywords: Liquefied natural gas, single mixed refrigerant, nitrogen expander liquefaction process, nitrogen self-recuperation, composite curves, compression power

NONMENCLATURE

Abbreviations	
NG	Natural gas
LNG	Liquefied natural gas
MR	Mixed refrigerant
SMR	Single mixed refrigerant
MITA	Minimum internal temperature approach
TLSO	Teaching learning self-study optimization
TDCC	Temperature-delta temperature composite curves
THCC	Temperature-heat flow composite curves
FLNG	Floating LNG
FPSO	Floating production storage and offloading
Symbols	
N2	Nitrogen
C1	Methane
C2	Ethane
C3	Propane
iC5	Iso-pentane

1. INTRODUCTION

Energy is an essential input for all the major sectors ensuring the human welfare and a good living standard. The US. Energy Information Administration has been estimated that the demand for energy is expected to rise by 48% from 2012 till 2040 [1]. To date, this global energy

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requirement is mainly satisfied through fossil fuels that have about 88% shares in total world's energy consumption [2,3]. However, natural gas (NG) is considered one of the cleanest fossil fuels, mainly due to the relatively lower air pollutants emissions, as shown in Figure 1 [1,4].

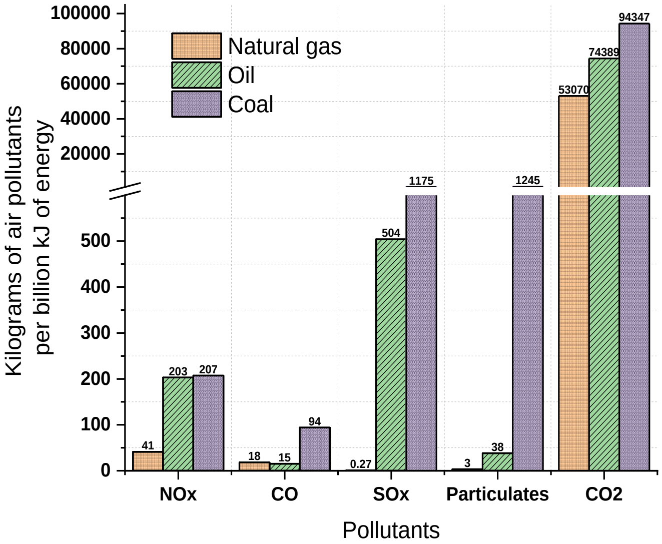

Fig 1 Natural gas emissions analysis in comparison with other available fossil fuels

Most NG reservoirs are located in remote areas, whereas NG is transported to markets in gaseous or liquid forms based on the distance. Transportation through pipelines is not an attractive option when long distances are to be covered. LNG is considered to be safer and more economic when to be transported over long distances [5]. However, liquefaction is an energy intensive process which makes it very expensive. This is because liquefaction requires refrigeration (up to about -161°C) which accounts for about 40-60% of the total cost for the plant [6].

To date, several technologies for LNG production have been developed for the onshore (C3MR and MFC etc.) and offshore (nitrogen-expander, SMR etc.) LNG production. The liquefaction process is chosen based on capacity, degree of complexity, and specific required energy, utilized as per their applicability is a specific site and location. However, the SMR (PRICO®) process is the dominant technology that has been adopted as a most suitable for offshore sites, owing to its small footprint, ease of operation, compactness, and straightforward design. However, the operating expenditures in terms of the energy required to liquefy NG is a major issue associated with SMR LNG processes. The SMR processes have a low energy efficiency as compared to onshore MR liquefaction process, nevertheless, higher than nitrogen expander-based LNG processes. The major portion of the required energy is used as compression power for the refrigeration cycle to liquefy NG.

The performance of SMR process has been improved through sole process optimization and process structure modification. For instance, Pham et al. [7] investigated high boiling components (butane and pentane) addition in conventional MR mixture adopting knowledge-based optimization approach. They modified the process structure by introducing phase separator and pump just before 4th compression stage. Lee et al. [8] presented a design strategy to find an optimal equipment size and operating conditions for SMR process under varying load. He et al. [9] presented a comprehensive optimization and comparative analysis of enhanced SMR and parallel nitrogen expansion LNG processes for offshore and small-scale applications. Qyyum et al. [5] improved the energy efficiency of traditional SMR process through an optimal replacement of JT valve with hydraulic turbine.

Since, SMR energy efficiency is still an ongoing issue. There is a need to design a process for offshore LNG production considering major constraints associated with offshore field such as compactness, ease of operation, and less complexity. In this context, we are going to present an enhanced SMR process that has a simple and compact design with significant improved energy efficiency. The optimal design of the proposed process was determined through teaching learning self-study optimization (TLSO) algorithm [10] that was coded in MATLAB 2017b. The proposed performance enhancement was analyzed using a commercial simulator Aspen Hysys® v10.

2. SELF-RECUPERATIVE SMR PROCESS

2.1 Process description and simulation

Figure 2 presents the simple process flow diagram of the proposed enhanced SMR process. The proposed liquefaction process was modeled in commercial simulator Aspen Hysys V10 at steady state condition. The fluid package of Peng-Robinson was assumed to estimate the components interactions based on process variables which further facilitate to simulate the LNG process by using the option of Lee-Kesler equation as it has been proved for the gases case at higher pressures. Basically, the liquefaction process contains two main streams; one consists on refrigeration loop which follows multistage compression and inter-stage cooling in order to enhance the pressure of refrigerant stream and second is the NG

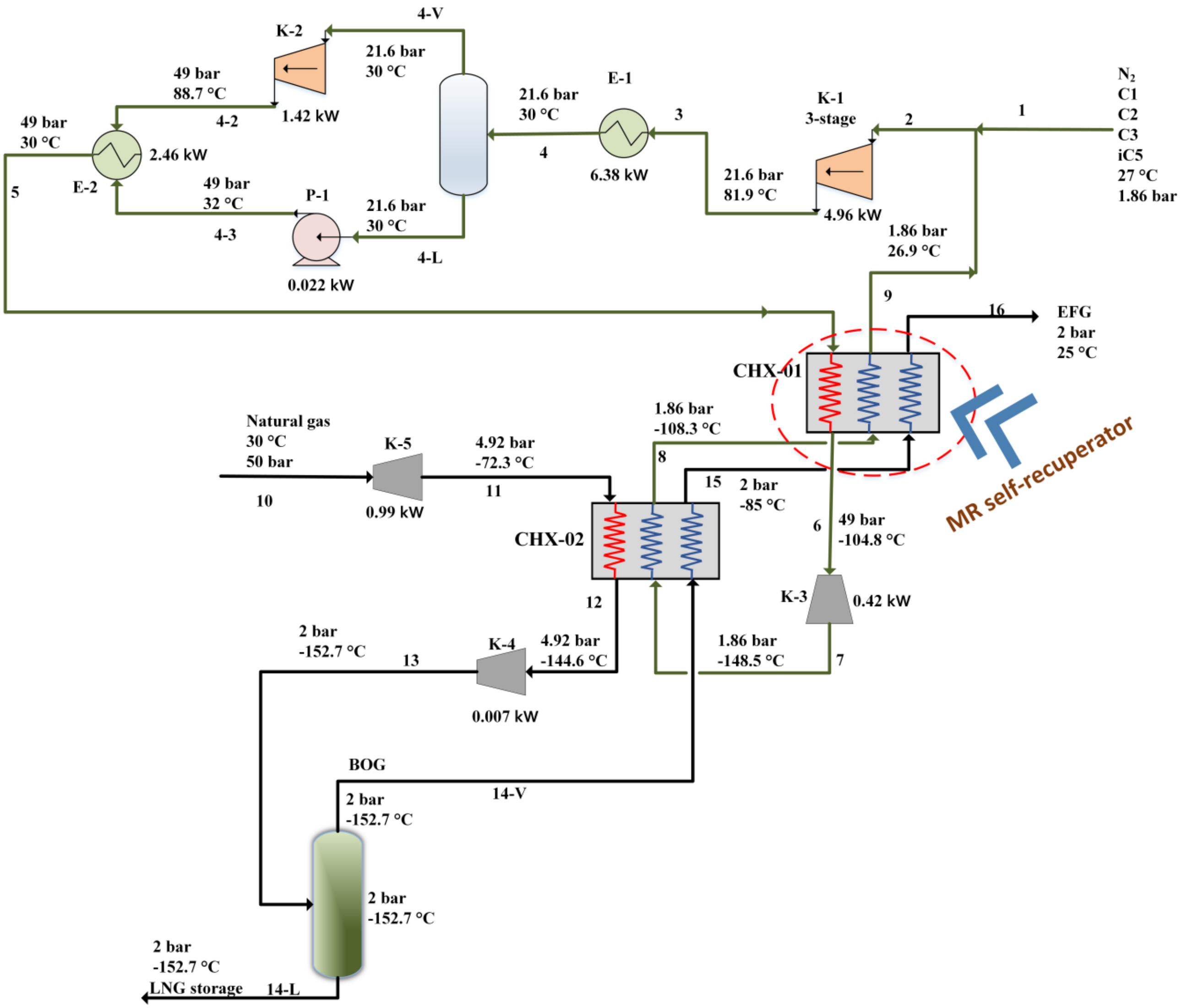

Fig 2 Process flow diagram of MR self-recuperator assisted SMR process

stream which after passing through cryogenic heat exchangers liquefies and stored for transportation.

The MR stream 1 is entered in the multistage compression section to increase the pressure by keeping the temperature consistent at 30 °C through inter-stage coolers while assuming the zero pressure drop in each inter-stage cooler. Whereas, the NG (stream-12) at high pressure is expanded to recover pressure energy that reduces the temperature to –72.3°C and also achieve some useful power i.e., 0.99 kW. The NG stream-16 is then sent to CHX-02 where, liquefaction and subcooling takes place at 4.92 bar and –144 °C.

3. RESULTS AND DISCUSSIONS

Process analysis of the four cases is carried out to estimate the energy efficiency of proposed liquefaction processes. The sequence of the design processes is shown in Figure 3.

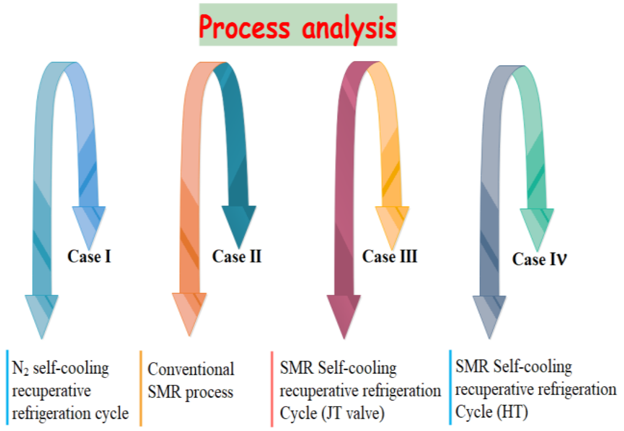

Fig 3 Process analysis comparison sequence

The major findings of the proposed liquefaction process are presented in Table 1, which describes the design specifications and variables in comparison to the case I and case II served as a base case. The mass flow rates of circulating refrigerants varies as per individual component involved in the refrigerant mixtures. However, the proposed case IV saves the total flow rate of 53%, 26%, and 20.6% as compared to case I, case II, and case III, respectively. It is noted from the process evaluation that SMR self-cooling recuperation (case IV) not only uses the lower flow rate of refrigerant but also reduces the expense on refrigerant usage which may provide the synergistic effect in liquefaction loops. Furthermore, the effect of pressure has significant importance in the refrigeration cycle that can be seen from the Table 1, the low and high pressure of the refrigerants in case III and IV is clearly reduced as compared to case I. This pressure reduction is mainly due to the presence of the C3 and iC5 which boost the refrigeration efficiency because of their high boiling temperature and high molar mass value compared to nitrogen. The resulted value of compression power reduced from 6.68 to 4.977 kW/kmol NG which saves 25.5 % of net energy reduction. In addition, the Hydraulic turbine case (case IV) generates power of 1.412 kW.

Table 1 Optimal findings of the proposed LNG process in comparison with the base case and previously published processes

Parameters	**Case-I** [11]	**Case-II**	**Case-III (JT)**	**Case-IV (HT)**
LNG product (liquid fraction)	0.95	0.94	0.92	0.94
MITA (°C)	3.0	3.0	3.0	3.0
Mass flow rate of nitrogen, m_{N2} (kg/h)	133	3.5	0.2	2.0
Mass flow rate of methane, m_{C1} (kg/h)	–	24.36	30.4	23.6
Mass flow rate of ethane, m_{C2} (kg/h)	–	3.5	0.1	0.5
Mass flow rate of propane, m_{C3} (kg/h)	–	25	19.7	20
Mass flow rate of i-pentane, m_{iC5} (kg/h)	–	28	28.2	16.2
Total refrigerant (kg/h)	133	84.36	78.5	62.3
Refrigerant low pressure (bar)	9.3	2.5	2.25	1.86
Refrigerant high pressure (bar)	88	45	53.05	49
Recuperation temperature (°C)	–48.4	–	–118	–104.8
Pressure ratio	1.75	2.65	2.20	2.27
Compression power (kW)	10.14	6.645	6.16	5.978
Generated power (kW)	3.46	–	0.975	1.412
Net power requirement (kW/kmol NG)	6.68	6.645	6.16	4.977
Relative net energy savings (%)	–	**0.5**	**7.8**	**25.5**

Furthermore, the performance of the liquefaction processes in terms of energy efficiency (or exergy efficiency) can also be illustrated through an analysis of the composite curves (TDCC and THCC) within cryogenic heat exchangers i.e., CHX-01 (MR self-recuperator) and CHX-02 (subcooling). Figures 4 and 5 show the composite curves for the MR self-recuperator and main LNG cryogenic heat exchanger, respectively.

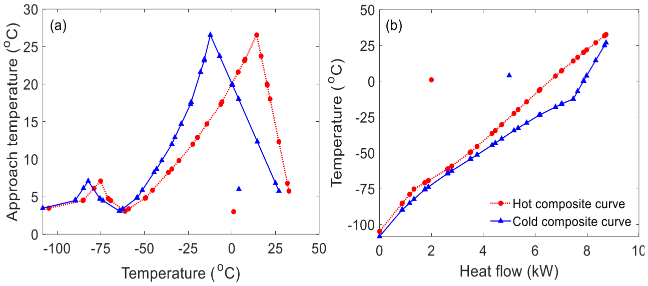

Fig 4 (a) TDCC and (b) THCC in the MR self-recuperator

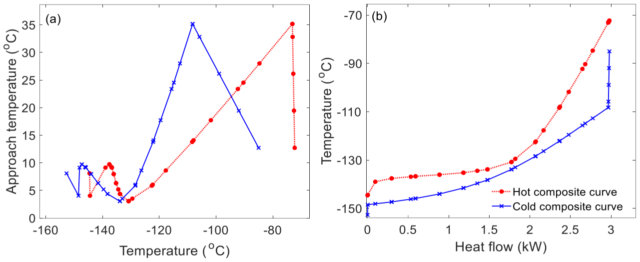

Fig 5 (a) TDCC and (b) THCC in the main LNG exchanger

4. CONCLUSIONS

The single mixed refrigerant liquefaction process for offshore LNG production has improved successfully by introducing a separate mixed refrigerant self-recuperator. The high pressure cold MR (exited from MR self-recuperator) gives significant cooling energy through isentropic expansion (cryogenic liquid turbine) phenomenon instead of isenthalpic. An integration of cryogenic liquid turbine reduce overall exergy destruction that leads to process performance enhancement. The TLSO approach has used and examined to get maximum potential advantages of the proposed enhancement in SMR LNG process. The TLSO approach can also be implemented to make an optimal design of other liquefaction processes as well as complex energy intensive cryogenic processes. The proposed LNG process will help of process engineers associated with FLNG-FPSO industry to solve energy-efficiency related issues with minimal capital investment.

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