Journal of Natural Gas Science and Engineering 33 (2016) 803–807

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

# Performance analysis of compressor unit for mixture refrigerant liquefaction cycle with a separator

Chao Cheng [a, c, *], L. Wang [b], G.B. Liu [b], Guoliang Qin [a], Yuanyang Zhao [b]

[a] School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an, PR China
[b] National Key Laboratory of Compressor Technology, Hefei General Machinery Research Institute, Hefei, PR China
[c] Xi'an Shaangu Power Co., LTD., Xi'an, PR China

ARTICLE INFO

*Article history:*
Received 19 January 2016
Received in revised form
31 May 2016
Accepted 2 June 2016
Available online 7 June 2016

*Keywords:*
Mixed refrigerant cycle
MR compressor
Interstage condensing
Performance modeling

ABSTRACT

A liquefaction process of mixed refrigerant cycle with a phase separator was proposed when multi-stage compressors are employed. The process includes a sub cycle in which the vapor refrigerant is separated in the separator to be fed to the second stage compressor and the liquid refrigerant leaving the separator is throttled to the required pressure in the second valve and then mixed with the return MR (Mixed refrigerant) stream before entering the precooler. A steady state simulation of the process was undertaken to study the influence of condensation pressure (first stage discharge pressure) on the performance of both compressor unit and liquefaction cycle. Although the lower condensation pressure results in less power consumption of the compressor, the minimum temperature difference of the main LNG heat exchanger is reduced, which causes the design of the main LNG heat exchanger to be difficult. Hence, choosing the condensation pressure becomes very important to the design and operation of the liquefaction cycles considering not only the energy efficiency but also the minimum temperature difference.


## 1. Introduction

Natural gas (NG) is an important energy source for different applications. When gas volumes are moderate, and/or transportation distances are long, the capital and operating costs of pipeline transport become prohibitive for transportation of NG. Therefore, liquefied natural gas (LNG) in tankers is often a preferred choice for bringing the gas to the market. There are different processes for liquefying natural gas, but very few are actually in use (Frank et al., 2008). The liquefaction process requires significant power demand so it is very important to achieve energy efficiency in the design and operation of liquefaction cycles. However, the energy efficiency is not the only important parameter. The system must also be cost effective, reliable, and tolerant of reasonably foreseeable feed changes. It must also be safely operated and maintained. And for certain application such as offshore plants, it should also be relatively compact.

The processes for liquefying natural gas can be classified as three groups, which are cascade process, mixed refrigerant (MR) liquefaction process and expander or turbine-based process. In order to meet a number of challenges including the demand of high efficiency and large capacity for liquefaction processes, the thermodynamic analysis on the liquefaction process must be evaluated (Mark et al., 2004; Tariq and Michael, 2007; Prerre, 2004; Tariq and Foster, 2004; Remeljej, 2006). To lower input power for the natural gas liquefaction process, it is crucial to reduce entropy generation due to the temperature difference between feed natural gas and refrigerants flow in LNG heat exchangers.

For the MR cycle liquefaction process, MR compressors are the key equipment component which fulfills the compression of MR. The compressors usually have two or more compression stages to achieve high energy efficiency with the required outlet pressure of MR. Condensation of MR often occurs in interstage coolers, which changes the mass flow rate and composition of MR flowing into the next stage (Gas Technology Institute, 2003; Cyrus et al., 2007; Nicholas et al., 2011). The effect of the condensation of MR must be taken into account when designing the MR compressor unit and the liquefaction cycle. Some parameters including the pressure of condensation (namely the first stage discharge pressure) are investigated herein and their influence on the performance of the compressor and heat exchanger are studied in this paper.

* Corresponding author. School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an, PR China.
*E-mail address:* shangu_cc@126.com (C. Cheng).

http://dx.doi.org/10.1016/j.jngse.2016.06.012
1875-5100/

### *1.1. Mixed refrigerant cycle with gas-liquid separator*

The MR cycle is widely used in LNG fields. Natural gas is a mixture of different hydrocarbons and its specific heat capacity varies considerably during its liquefaction process, hence a variety of combined refrigerants is needed to efficiently liquefy natural gas. The performance of the MR cycle operating with a single evaporation pressure may be improved by using what is known as phase separator economizer as shown in Fig. 1. The first stage results in some vaporization. The vapor is removed from the separator to be fed to the second compression stage. The liquid leaving the separator is throttled to the required pressure in the valve and then mixed with the return MR stream before entering the precooler.

A schematic of the MR cycle with gas-liquid separator is shown in Fig. 1. Feed gas (S9) enters the precooler (E3) with a pressure of 50 bar and temperature of 40 °C and is cooled to the temperature of −10 °C (S10) by vaporizing mixed refrigerant. It is cooled to −155 °C (S14) in the main heat exchanger (HX, E4) and is expanded in a throttling valve (V2) to −162.94 °C and 1 bar (S15). The produced LNG (S15) is sent to the flash tank where LNG (S17) and flash gas (S16) can be separated. The ratio of the flash gas to the inlet natural gas is 0.074, which means that 92.6% of natural gas is converted to LNG product. The MR vapor of temperature 40 °C and pressure 42.5 bar (S6) is cooled to −10 °C (S11) in the precooler and −155 °C (S12) in the main HX, respectively. The pressure of cooled MR is reduced adiabatically in the throttling valve (V1) to 3 bar and its temperature is decreased to −159.88 °C (S13). Then it is introduced to the cold end of the main heat exchanger to provide refrigerating capacity to both MR and NG streams. The vaporized refrigerant at 3 bar and 30 °C (S21) is returned to the first stage compressor and its pressure and temperature is increased to 18 bar and 131.24 °C, respectively. The compressed MR (S2) is cooled in interstage cooler (E1) to temperature of 40 °C (S3). Then 12.3% of MR as liquid (S7) is removed from the separator (F1) and cooled to −15 °C liquid steam (S8) in the precooler (E3). Its pressure is dropped to 3 bar in the throttling valve (V3) and recycled to precooler (E3) after mixing with the returned MR (S19). The pressure and temperature of the vapor MR becomes 42.5 bar and 113.4 °C (S5) after the second compression stage and is cooled to 40 °C (S6) before it flows into the precooler.

The compositions of the NG feed gas as well as MR used in this paper are listed in Table 1. The flow rate of NG feed is 50 × $10^4$ $Nm^3$/D. The compressor suction volume flow rate is 18 983.3 $m^3$/h.

A detailed model for the MR cycle is developed in using multi-flash for calculation of physical properties for the natural gas and the mixed refrigerant (Singh and Hovd, 2006). The GERG-2008 mixture model for natural gas fluids is used for both the refrigerant and the natural gas (Lemmon et al., 2010). It is essential to develop a model for the main components in the cycle, namely the heat exchanger, valve, compressor, condenser and flash tank. Valves are modelled as isenthalpic processes. A brief description of models for the mixed refrigerant compressor unit and the LNG heat exchanger is given below.

**Table 1**
Compositions of NG feed gas and MR (mol%).

| | $CH_4$ | $C_2H_4$ | $C_3H_8$ | i-$C_5H_{12}$ | $N_2$ | $C_2H_6$ |
|---|---|---|---|---|---|---|
| MR | 19.5 | 34 | 17.5 | 18.5 | 10.5 | / |
| Feed | 92 | / | 2 | / | 2 | 4 |

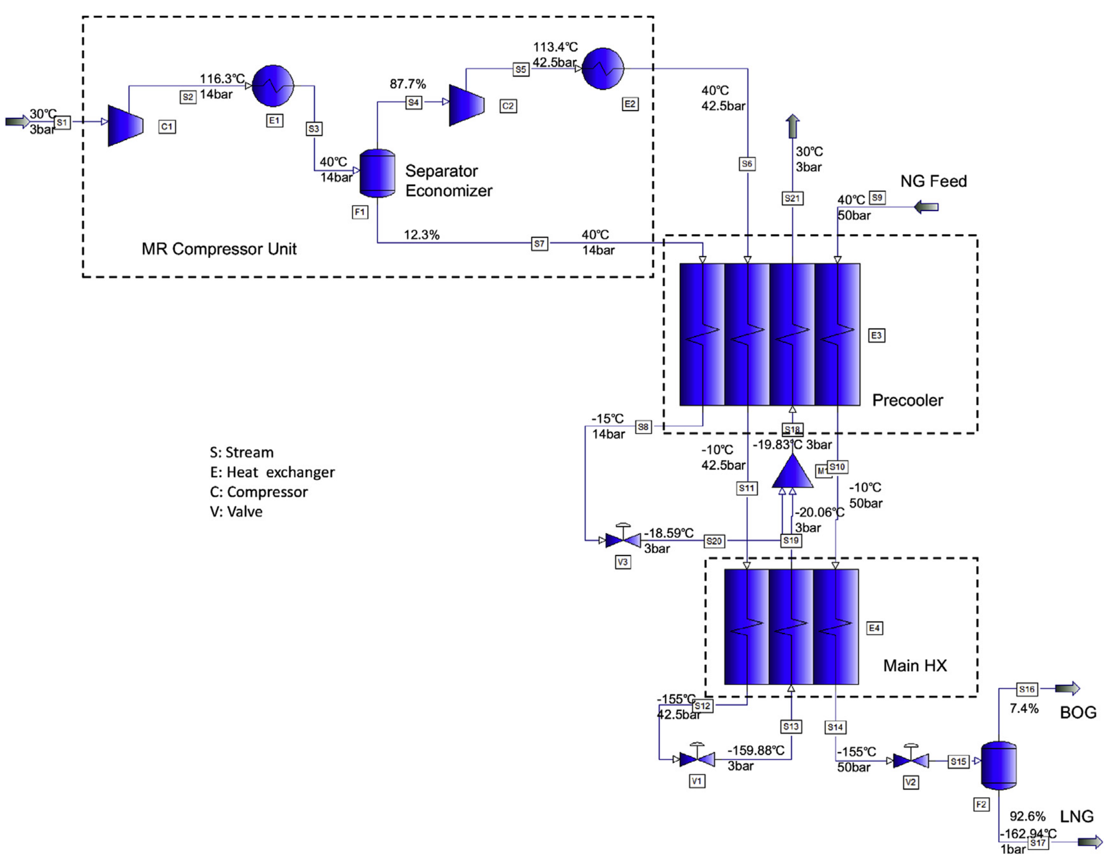


**Fig. 1.** MR cycle operating with separator economizer.