Centrum Rzeczoznawstwa Budowlanego

Inżynieria Bezpieczeństwa Obiektów Antropogenicznych 2 (2021) 43-48
https://inzynieriabezpieczenstwa.com.pl/

Inżynieria Bezpieczeństwa Obiektów Antropogenicznych

Modification of the cascade methane liquefaction process to improve the efficiency of the system

Maciej CZYŻ[1] and Andrzej GRZEBIELEC*[1]

[1]Faculty of Power and Aeronautical Engineering, Warsaw University of Technology, Warsaw, Poland

Abstract

In recent years, the dynamic development of the LNG industry has been observed. This is largely due to the transition of many countries from coal-based energy to greener energy. Natural gas is regarded as an intermediate fuel. Natural gas can be transported by pipeline, but in many cases it is more economical to transport it in a liquefied form. The liquefaction process is very energy-consuming, which is why many researchers are focused on optimizing this process. This work is an attempt to optimize the operation of the basic cascade natural gas liquefaction system. The proposed modifications contribute to a significant reduction in the costs of the liquefaction process.

Keywords: LNG, energy efficiency, liquefaction of natural gas

1 Introduction

Natural gas is rapidly gaining importance in today's world. Since the 1970s, it has been one of the fastest growing branches of energy, affecting most regions of our planet. It is seen as an ecological fuel that can replace crude oil and may become a key fuel for mankind in the future [4, 8]. In Fugure 1 there is shown World consumption of Natural Gas.

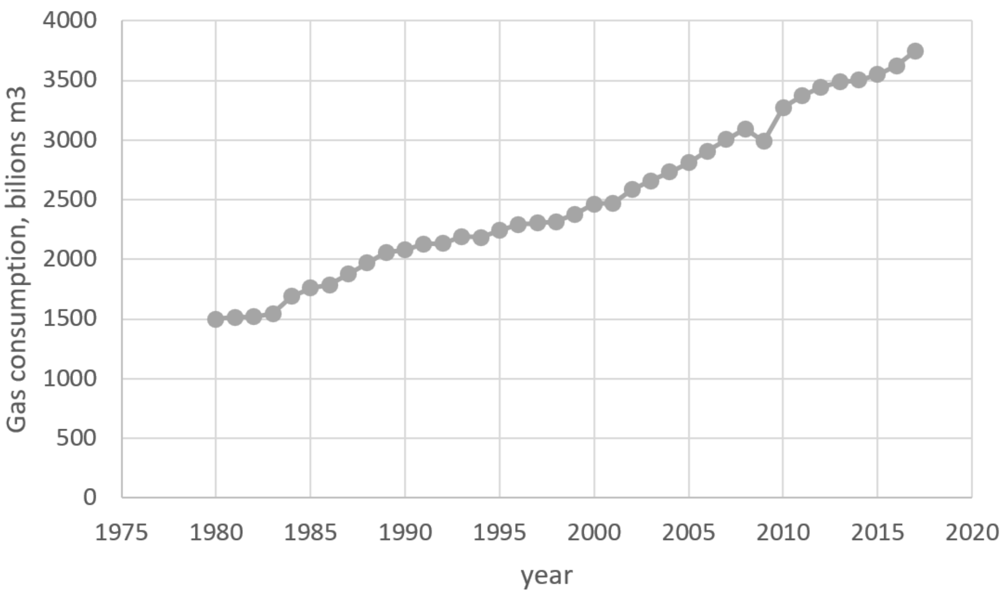

Figure 1. World consumption of Natural Gas [17]

*Corresponding author: E-mail address: (andrzej.grzebielec@pw.edu.pl) Andrzej GRZEBIELEC

https://dx.doi.org/10.37105/iboa.112
Received 2 April 2021
Available online 30 June 2021
ISSN 2450-1859, eISSN 2450-8721
Published by Centrum Rzeczoznawstwa Budowlanego

Along with the exploitation of new, hard-to-reach natural gas deposits, this fuel is transported through pipelines less and less often. Transporting natural gas in liquefied form has gained importance, and gas liquefaction and regasification facilities are being built on every continent [9, 10, 15]. The modernization of existing installations, which are being rebuilt in order to increase their capacity or improve their efficiency, is also of great importance [2, 3, 5, 14].

The most important process related to LNG is the liquefaction process due to its cost. The sprinkling process is responsible for up to 50% of the costs of the final price of the natural gas. There are many methods for liquefying natural gas, but there are usually three basic ones - the cascade cycle, the auto-cascade cycle, and the turboexpander expansion cycle [5, 11, 13]. The first one is currently the most widely used, and its main advantage is high efficiency. The auto-cascade cycle allows for quick adjustment of the operating parameters of the system to the changing composition of the liquefied gas, while the turboexpander installations are widely used in small condensing stations [1, 6, 7, 9, 10, 12, 16].

2 Basic cascade system

The cascade system shown in Figure 2 is the most widely used liquefaction system for natural gas. In order to liquefy the natural gas, it was cooled in two exchangers. The first of them (in which the cooling medium is propane) allows to reduce the temperature of natural gas to a temperature of - 40^{o}C. In addition, ethylene is also cooled in this exchanger, which is used as a coolant in the second exchanger. The second exchanger allows the temperature of the methane to be reduced to - 110^{o}C. The natural gas then passes through a throttle valve where its temperature drops to -162^{o}C. In the next stage, natural gas goes to the tank, where its condensate is discharged, while the gas phase is discharged and returned to the entrance to the condensation system.

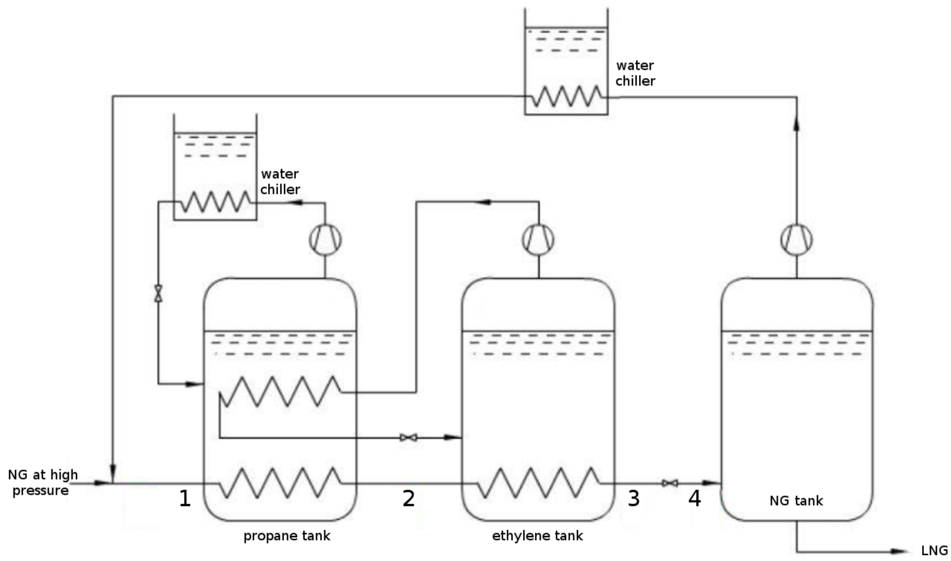

Figure 2. Basic Natural Gas liquefaction system

Figure 2 shows the circulation of methane through all three tanks.

Where point represents:

- 1-2 - Cooling of natural gas from the initial temperature of 30^{o}C to the temperature of -40^o C in the first heat exchanger, the cooling medium is propane tank (working as propane evaporator).
- 2-3 - Cooling the natural gas down to the temperature of -110^{o}C (cooling and condensing) in the second heat exchanger, the cooling medium is ethylene tank (working as ethylene evaporator).
- 3-4 - Methane expansion in J-T valve, allowing to lower its temperature to -162^{o}C, which allows for the condensation of a part of the methane condensed in the system and achieving the degree of dryness x = 0.395.

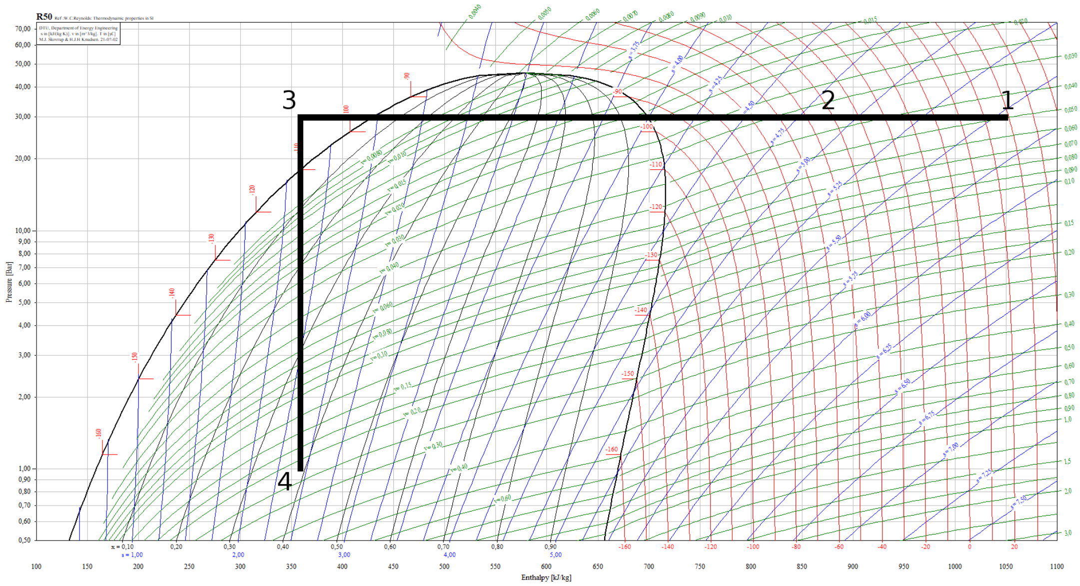

Figure 3. Methane cycle in a cascade liquefaction system

For the cascade system presented above, the power of the compressors was determined for the flowing methane with the stream: $\dot{m}_{NG} = 1 \left[\frac{kg}{s}\right]$. The EER (Energy Efficiency Ratio) for the propane system and for the eylene system was determined for the parameters of the methone system operation, which were presented for Fig. 3. The EER for the propane cycle is:

$$EER_{R290} = 1.31[-] \tag{1}$$

Which gives a propane compressor power of 1012 kW (remember that the propane system, apart from methane cooling, is also an ethylene system condenser). The EER for the ethylene cycle is:

$$EER_{R1150} = 0.83[-] \tag{2}$$

which makes the power of the ethylene compressor 880 kW. Compressing methane (fresh and recirculated) requires a compressor with a power of 383 kW. So the total power of all compressors is

$$\dot{Q}_{tot} = \dot{Q}_{R1150} + \dot{Q}_{R290} + \dot{Q}_{NG} = 2025\,[kW] \tag{3}$$

where

$\dot{Q}_{R290}$ - propane compressor power

$\dot{Q}_{R1150}$ - ethylene compressor power

$\dot{Q}_{NG}$ - natural gas compressor power

Since the degree of dryness is 0.395, it means that to continuously condensate 1 kg of LNG, the power should be 3347 kW.

3 System after modifications

The main part of the cycle that affects its efficiency is the compression process. When the refrigerant is compressed, its temperature rises. In the basic system, the temperature of propane at the compressor outlet can reach even 80^{o}C, and ethylene is at 120^{o}C. In addition, achieving such high temperatures requires the use of compressors that maintain their operating parameters in such conditions, which usually increases the cost of their implementation and affects their power consumption. In order to reduce the final temperature in the compression process, it was decided to extend the propane system with an intercooler, and to add an ethylene water cooler. In this modification, the compression process will take place in two compressors between which the gas will be cooled before entering the second compression stage. Additionally, the propane evaporation temperature was lowered by 10K and there was added water chiller for ethylene cycle. Changes are shown in Figure 4.

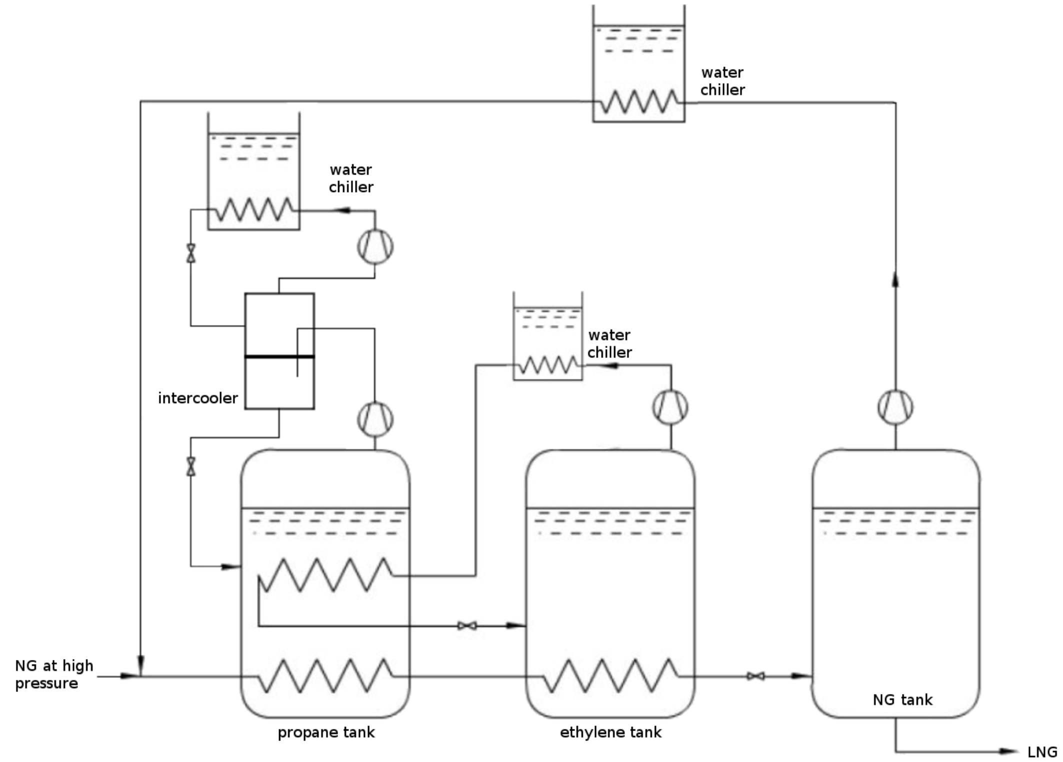

Figure 4. System after modification

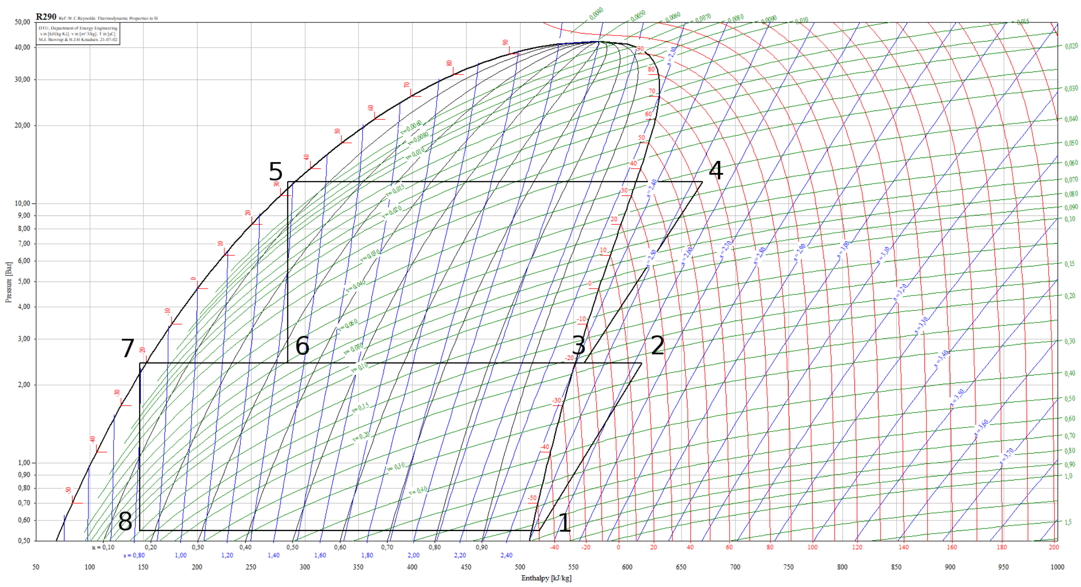

Figure 5. Modified propane cycle

The schematic diagram of the new propane cycle is shown in the lnp-h diagram in Figure 5. For this cycle EER of propane cycle is equal to

$$EER_{R290} = 1.49[-] \tag{4}$$

The power of propane compressor is also reduced because a part of ethylene condensation process is done by water chiller. So in this case propane compressors capacity is 624 kW.

As the evaporation temperature in the propane system decreased, the temperature in the ethylene system also decreased. As a result, the EER coefficient for this system was:

$$EER_{R1150} = 1.03[-] \tag{5}$$

For this EER, the power of the ethylene compressor will change to: 508 kW. Compressors for NG remained unchanged. So the total power of all compressors is

$$\dot{Q}_{tot} = \dot{Q}_{R1150} + \dot{Q}_{R290} + \dot{Q}_{NG} = 1515\,[kW] \tag{6}$$

Thanks to the changes, the power of the compressors was reduced by 510 kW.

4 Conclusions

The process of liquefying natural gas is a process that requires large financial outlays. The costs associated with liquefactionit are responsible for 40-50% of the LNG price for the end user, which is why so much attention is paid to improving its efficiency. Thanks to the modification of temperatures and appropriate selection of mass streams of refrigerants, it is possible to reduce energy consumption in this process, which results in a reduction in the final price of liquefied natural gas. Introduce a two-stage compression system with intercooling on the propane circuit to lower the temperature of the refrigerant at the end of the compression process, which significantly reduces the losses associated with this process. In this case operation costs was reduced by 25%. The results of the calculations carried out in this work showed that the appropriate optimization of the system operating parameters can significantly reduce the power demand for the system operation. In addition, the use of a two-stage compression process allows for an additional reduction in power demand. Optimization of LNG-related processes will be the subject of many studies, and its importance will grow along with the exploitation of subsequent deposits and the growing competition on the natural gas market.

References

1. Agarwal, R. *et al.* LNG Regasification Terminals: The Role of Geography and Meteorology on Technology Choices. *Energies* **10.** ISSN: 1996-1073 (2017).
2. Baryłka, A. The impact of fire on changing the strngth of the underground shelter structure. *Rynek Energii* **146,** 71–75 (1 2020).
3. Cardella, U., Decker, L., Sundberg, J. & Klein, H. Process optimization for large-scale hydrogen liquefaction. *International Journal of Hydrogen Energy* **42,** 12339–12354. ISSN: 0360-3199 (2017).
4. *Chevron Oil Company, 2020 World LNG Report* in. 27th World Gas Conference Edition (2020).
5. Ding, H., Sun, H. & He, M. Optimisation of expansion liquefaction processes using mixed refrigerant N2–CH4. *Applied Thermal Engineering* **93,** 1053–1060. ISSN: 1359-4311 (2016).
6. Giametta, R. E. H. *Integration of LNG Regasification and Air Separation Units* (NTNU, 2017).
7. *Guide for building and classing offshore LNG terminals* (American Bureau of Shipping ABS Plaza 16855 Northchase Drive Houston, TX 77060 USA, 2004).
8. He, T., Karimi, I. A. & Ju, Y. *Review on the design and optimization of natural gas liquefaction processes for onshore and offshore applications* 89–114 (2018).
9. Leffler, W. *Natural Gas Liquids: a nontechnical guide* ISBN: 9781593703240 (2014).
10. Martin, P.-Y., Pigourier, J. & Boutelant, P. *Liquefin: an innovative process to reduce lng costs* in *22nd World Gas Conference* (Tokyo, Japan, 2003).
11. Mokarizadeh Haghighi Shirazi, M. & Mowla, D. Energy optimization for liquefaction process of natural gas in peak shaving plant. *Energy* **35,** 2878–2885. ISSN: 0360-5442. https://www.sciencedirect.com/science/article/pii/S0360544210001374 (2010).

12. Mokhatab, S., Mak, J., Valappil, J. & Wood, D. *Handbook of Liquefied Natural Gas* ISBN: 978-0-12-404585-9 (Elsevier Inc., 2014).
13. Molenda, J. *Gaz ziemny. Paliwo i surowiec* (Wydawnictwa Naukowo Techniczne, 1996).
14. Owczarek, M., Owczarek, S., Baryłka, A. & Grzebielec, A. Measurement Method of Thermal Diffusivity of the Building Wall for Summer and Winter Seasons in Poland. *Energies* **14.** ISSN: 1996-1073 (2021).
15. Quirijns, S. *LNG Regasification Terminals, A literature study into the world of LNG. A technical feasibility study for constructing a sustainable LNG regasification terminal in Yuzhny, Ukraine* (Delft University of Technology, 2015).
16. Steuer, C. *Outlook for Competitive LNG Supply* ISBN: 978-1-78467-131-0 (Oxford Institute for Energy Studies, 2019).
17. *World Natural Gas Statistics - Worldometer* `https://www.worldometers.info/gas/` (2021).