CHEMICAL ENGINEERING RESEARCH AND DESIGN 90 (2012) 1500–1505

Contents lists available at SciVerse ScienceDirect

Chemical Engineering Research and Design

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

Flexible and cost-effective optimization of BOG (boil-off gas) recondensation process at LNG receiving terminals

Yajun Li[a,*], *Xingshui Chen*[a], *Ming-Hsiung Chein*[b]

[a] *Key Lab of Heat Transfer Enhancement and Energy Conservation of the Ministry of Education, South China University of Technology, Guangzhou, Guangdong Province, China*
[b] *Yung-An LNG Receiving Terminal, CPC Corporation, Taiwan*

ABSTRACT

In view of high energy consumption and poor flexibility in boil-off gas (BOG) recondensation operation at liquefied natural gas (LNG) terminals, a flexible and cost-effective optimization including the control system and flow process has been proposed. The optimized control system maintains BOG recondenser pressure via the condensing LNG flow and recondenser liquid level via bypass LNG flow. A BOG recondensation process with pre-cooling operation utilizes high-pressure pump LNG to pre-cool compressed BOG before it is directed into recondenser. The engineering application in a case of 6.69 tons/hour (t/h) BOG and LNG output fluctuating between 49 t/h and 562 t/h shows, after the flexible and cost-effective optimization, that process energy decreases 91.2 kW, more 1.28 t/h BOG is recovered when LNG output load reaches the valley, and the operation stability is well improved.

Keywords: LNG; BOG; Recondenser; Compressor; Optimize

1. Introduction

Natural gas (NG) is one of the promising clean energy resources, which plays a role of improving the atmospheric environment, optimizing primary energy consumption structure and easing the strained petroleum supply. NG consumption in China has been growing quickly in recent years, although China relies heavily on its coal supply. By 2020, the demand for NG in China is projected to be 450 billion cubic meters (BCM). However, domestic production of NG is estimated at 270 BCM, leaving a shortfall of 180 BCM of supply to be met through importing international NG (Yifei and Yanli, 2010). The first two LNG receiving terminals in China have commenced their commercial operation in Guangdong and Fujian province. To meet the increasing demand for NG, more LNG receiving terminals in plan will be built in Yangtze River Delta Region, Bohai Rim and Pan-Pearl River Delta Region. By 2020, total LNG receiving facilities with an annual scale of 50 million tons could make NG account for 12% in China's total energy budget (Li and Bai, 2010; Shin et al., 2008; Lin et al., 2009).

Owing to the physical nature of NG, the most economical way for transportation over long distances is by liquefaction of the gas and shipment on special LNG tankers. Through the liquefaction process, NG composed of mainly methane is cooled to about −160 °C at atmosphere pressure. Due to the inflow of heat transfer from the surroundings to cryogenic LNG, LNG is unavoidably vaporized generating BOG (≤0.05%/day, mass fraction) in LNG storage tanks and liquid-filled pipe lines. In addition, LNG ship unloading operation also contributes to BOG generation. Therefore, how to recover BOG is an essential issue in LNG receiving terminals. BOG recondensation system is widely used to liquefy and recover BOG due to its 30–60% higher energy-utilization efficiency than that of compressing BOG directly to distribution pipeline Mabuchi Nobuhiro (Osaka Gas Co., 2006). A number of representative patents dealing with BOG recondensation are available (Darron Granger, 2004; Engdahl, 2002, 2008; Rajeev Nanda, 2007). Also, Kim et al. and Shin et al. studied the economic aspects of handling BOG (Kim et al., 2001; Shin et al., 2007). Park et al. investigated how to minimize the cost in terminal operation according to the variation of LNG demand (Park et al., 2010). To address the

* *Corresponding author*. Tel.: +86 20 87112044; fax: +86 20 87114677.
E-mail address: liyajun@scut.edu.cn (Y. Li).
Received 1 June 2011; Received in revised form 23 December 2011; Accepted 25 January 2012
0263-8762/$ – see front matter © 2012 The Institution of Chemical Engineers. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.cherd.2012.01.013

Nomenclature

LNG	liquid natural gas
BOG	boil off gas
BC	BOG compressor
LP	low pressure pump
P_R	pressure within recondenser (barg)
P_{HPs}	pressure of HP suction header (barg)
Q_{LNG}	LNG used for recondensation flow rate (m^3/h)
P_B	LNG saturation pressure of HP suction side under T (bar)
T_s	saturation temperature of BOG recondensation (°C)
T_c	critical LNG temperature at the suction header of HP (°C)
NG	natural gas
ORV	open rack vaporizer
BR	BOG recondenser
HP	high pressure pump
L_R	liquid level within recondenser (%)
RCB	ratio calculation block
Q_{BOG}	BOG flow rate (m^3/h, standard condition)
T	LNG temperature at HP suction side (°C)
M_1	necessary quantity of LNG for BOG recondensation (t/h)
M_2	critical quantity of LNG output considering HP operation (t/h)

comprehensive process reliability in LNG terminals, Jung et al. investigated BOG treatment from the viewpoint of operator practices (Jung et al., 2003).

Worldwide demand for NG is increasing year by year. More and more LNG plants have been under construction subsequently. However, the existing BOG recondensation systems (such as at Montoir de Bretagne terminal in France, Dahej terminal in India, and Da-Peng terminal in China) have faced difficulties in operating BOG recondensation and it consumes too much energy as NG output to end-users changes dramatically. In order to solve conventional design problems occurred during BOG recondensation operation, this work analyzes and optimizes the BOG condensing system at China's first LNG receiving terminal (Da-Peng terminal). This optimization which is expected to help the design improvement for other BOG recondensation processes has reduced energy consumption and improved flexibility of recondensation operation.

2. Existing BOG recondensation process

Da-Peng LNG receiving terminal has three cryogenic fully contained LNG storage tanks and receives annually 3.7 million tons of imported LNG from Australia. Fig. 1 presents the schematic diagram of LNG receiving and vaporization system with BOG recondensation operation at Da-Peng terminal, and Table 1 tabulates the components of imported LNG. The

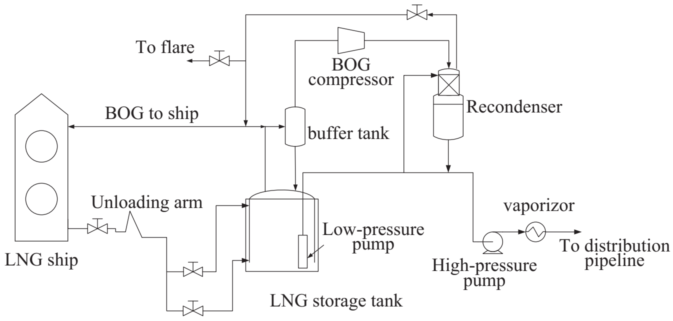

Fig. 1 – LNG receiving and regasification system at Da-Peng terminal.

storage temperature is about −160 °C and the pressure is 0.153 barg under holding mode. Normally 6.69 t/h BOG is treated. As Fig. 1 depicts, LNG from low pressure pumps (LPs) is split into two streams. One stream (hereinafter, referred to as condensing LNG stream) is directed into the top of BOG recondenser (BR) to condense BOG, which has been compressed to 8 barg by BOG compressor (BC), and the other stream (hereinafter, referred to as recondenser bypass LNG stream) mixes with the condensate out of the recondenser. LNG is finally pressurized to 90 barg by high pressure pumps (HPs) before it is routed to the open rack vaporizer (ORV), where LNG performs indirect heat exchange with seawater to convert into 0 °C vapor form.

The key factors that determine BOG recondensation performance are the operating pressure and the ratio of condensing LNG to BOG (LNG/BOG). BC with a lower outlet pressure saves energy and proper LNG/BOG ratio enables BOG re-liquefaction effectively (Yang and Li, 2009).

2.1. *Analysis of existing control system to BOG recondensation process*

BOG recondenser is the core device for BOG recondensation and acts as a buffer vessel for HP. How to maintain the pressure and the liquid level within BOG recondenser (P_R and L_R) steady is an important issue for a BOG recondensation system. Fig. 2 illustrates the existing control system to BR operation at Da-Peng terminal.

2.1.1. *Flow rate and pressure control*

BOG flow is designed at 6.69 t/h of capacity. P_R is normally at 8 barg. Recondenser pressure controller PIC-1 ensures stable HP suction pressure to prevent HP from cavitations by regulating the flow rate of recondenser bypass LNG, which increases or decreases via pressure control valves PCV-1 and PCV-2. On the other hand, the condensing LNG flow rate is regulated by the control valve FCV. The condensing LNG flow rate derives from the following equations:

$$Q_{LNG} = \frac{Q_{BOG}}{C_f \times P_{HPs} \times 10} \tag{1}$$

It is fixed by the ratio calculation module (RCB) in FX1, where: Q_{LNG} (m^3/h) is volume flow of condensing LNG; Q_{BOG} (Nm^3/h,)

Table 1 – Components of LNG from Australia.

	Components						
	Methane	Ethane	Propane	i-Butane	n-Butane	i-Pentane	Nitrogen
Mol (%)	88.774	7.542	2.588	0.454	0.562	0.004	0.074