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Integrating Recovered Jetty Boil-off Gas as a Fuel in an LNG Plant

Danan S. Wicaksono,[a] Iftekhar A. Karimi,[a] Hassan Alfadala,[b] Omar I. Al-Hatou[c]

[a]*Department of Chemical and Biomolecular Engineering, National University of Singapore, Singapore 117576, Singapore, g0500048@nus.edu.sg; cheiak@nus.edu.sg*
[b]*Department of Chemical Engineering, Qatar University, Doha, Qatar, alfadala@qu.edu.qa*
[c]*Qatargas Operating Company Ltd., Ras Laffan Industrial City 22666, Qatar, OAlhatou@qatargas.com.qa*

Abstract

Liquefied natural gas (LNG) is increasingly becoming an attractive alternate for crude oil and its usage is expected to grow tremendously in the coming years. Liquefaction of natural gas is a highly energy-intensive process. Because of its cryogenic nature, vapors called as boil-off gases (BOG) are generated at various places in an LNG plant due to heat leak, vapor displacement, flashing, and hot contact. The BOG from storage tanks, called as tankage BOG is usually compressed and exported to the plant fuel system. However, in some LNG plants, there exists another source of BOG; the one from intermittent loading, called as jetty BOG. As plant capacities grow and economic efficiency becomes important, it makes sense to integrate the jetty BOG optimally into the existing fuel gas network. We propose a novel superstructure and nonconvex mixed-integer nonlinear program for addressing this problem. An industrially based case study showed that our approach is efficient and practically useful.

Keywords: liquefied natural gas, boil-off gas, fuel gas network, process integration, mixed-integer nonlinear programming, reduced superstructure, energy conservation

1. Introduction

A natural gas liquefaction process is highly energy-intensive. Thus, efficient use of energy is very important. A key facility of LNG plant is the fuel gas system which is part of the LNG plant utilities section. The function of this facility is to satisfy the plant energy demands. It is unique because the sources of fuel are coming from the plant itself. The fuel itself is used for generating power in the form of both electricity and steam to support plant operations in onsite and offsite area.

Fuel gas system is designed considering the availability of tail gas in the plant, equipment design requirements as the user of fuel gases and these have to be balanced in such manner that no flaring occur. Fuel gas system in a LNG plant is very specific depending on the plant design as a result of its process and equipment.

It is not trivial to determine the best and technically feasible scenario for fuel gas mixing and distribution. In practice, several most promising scenarios are considered case by case. Wicaksono et al. [1] discussed the problem of finding the optimal synthesis of grass-root fuel gas networks in which it was represented, modeled, and solved to global optimality in a systematic way. They proposed a novel *superstructure* [2] and mixed-integer nonlinear program. They further applied the approach to industrial case study in determining optimal synthesis of such network where significant improvement was achieved. This problem was further extended to simultaneous synthesis and operation optimization problem [3].

In this work, we treat jetty BOG as an additional source of fuel. It is desirable to integrate this additional fuel into the existing fuel gas network. However, integrating this additional fuel source optimally and satisfactorily within the existing fuel gas network is not a trivial task, as extra piping and/or equipment may be needed to accommodate this modification. Furthermore, this should be done without affecting the fuel quality requirements of existing equipments. Due to the combinatorial nature of the problem, industry seems to be using heuristic procedures based on empirical judgments. In this study, we tackle this integration problem as a nonconvex mixed-integer nonlinear program using a superstructure of all possible design options. We illustrate the application of our model using industrial case study.

2. Problem Statement

We consider the optimal configuration of an integrated fuel gas network in an LNG plant. The network consists of fuel gas sources, sinks, mixers, fuel sinks, and connecting pipelines. The objective of this study is to design a network which gives minimum fuel consumption.

The decisions which have to be determined are mixing and distribution scenarios. No chemical reactions, separations, and phase changes involved.

Conditions of fuel sources, such as flow rate and composition are determined by the operating mode. The requirements imposed by fuel sinks are allowable Wobbe index (WI) range and fuel energy content. Our problem can be summarized as follow:
given:

1. sources and sinks (existing and additional) and their characteristics
2. fuel supply and demand, including quality requirements

determine:

1. optimal fuel mixing and distribution scenario
2. minimum fuel consumption

2.1. Fuel sources

Fuel sources are located at the upstream of fuel gas network. They are gases which can be utilized as fuel. There are two major sources for fuel: tail gases and feed gases. Tail gases are leftover gases which are neither not product or recyclable. These gases correspond to production losses and therefore should be minimized by using them fully as fuel gases if possible. Fuel gases taken from feed are used to fill the gap between plant energy demand and the amount of energy which can be provided by tail gases. However, the usage of feed as fuel decreases the quantity of LNG produced and hence should be minimized.

2.2. Fuel sinks

Fuel sinks are located downstream of the fuel gas network. They transform potential energy contained by fuel into more practically useful form. Typical fuel consumers are process driver turbines, power generator turbines, boilers, and incinerators. Process turbines drive the refrigerant compressors. Power turbines and boilers generate electricity and steam respectively.

2.3. Fuel source – sink compatibility

Every sink has different fuel requirements based on its design while each fuel source has its own characteristic such as LHV (Lower Heating Value) and composition. The interchangeability between these various fuels is measured by WI. Thus, each sink must be fed by fuel which satisfies a certain range of WI. In order to achieve the desired WI specification, some operations such as mixing required.

3. Methodology

In this work, we consider all possible scenarios in one superstructure and then formulate the selection of the best structure as an optimization problem. The problem is then solved to global optimality. The proposed approach is general in that it can be extended to any numbers of sources and sinks.

Fig. 1. shows the superstructure for this problem. Nodes i, m, and o represent fuel sources, mixers, and sinks, respectively while arcs represent interconnection between fuel sources, mixers, and sinks. It should be noted that the number of mixers in the superstructure is equal to the number of sinks concerned. One source node does not necessarily correspond to one physical source. Sources which have identical properties can be lumped into a single node. Similar concepts can also be applied to sinks. Using this strategy called *reduced superstructure*, the size of the problem is reduced and so does the computational effort required.

Mathematical formulation is developed based on the given superstructure in such manner that nonlinearities are minimized. The model incorporates overall and component material balance as well as energy balance. The resulting formulation is a mixed-integer nonlinear programming (MINLP) problem.

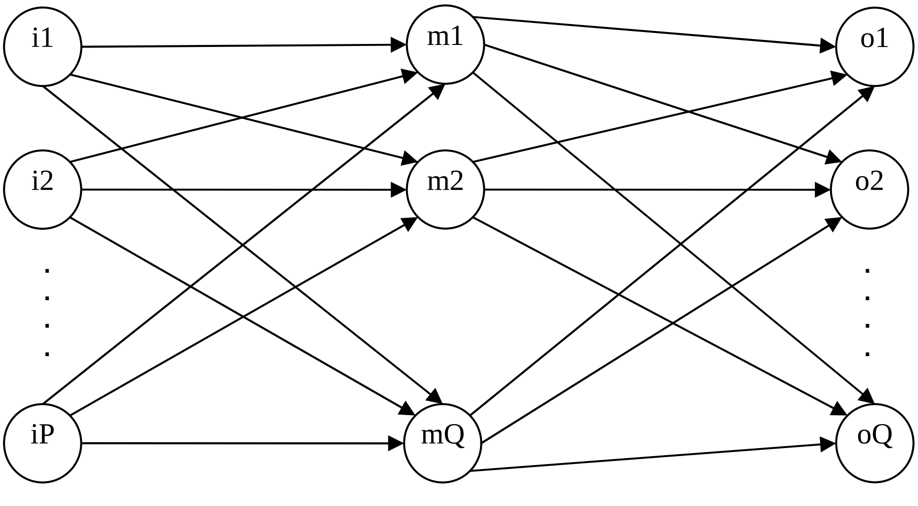

Fig. 1. Fuel gas network superstructure with P sources and Q sinks

In order to ensure that the network only has one layer of mixing, we introduce the following constraints.

$$\sum_{m} zq(m,o) \le 1 \ \forall o$$

Binary variable zq(m,o) models the interconnection between mixer m and sink o. Therefore, nonconvex bilinear terms in the component material balance can be exactly linearized. This reduction in nonlinearities significantly improves the computational performance of the MINLP.

4. Case study

An industrial fuel gas network in an LNG plant comprising three trains as depicted in Fig. 2. was considered in this work. Later on, we integrate one additional fuel source which is jetty BOG. This study concerns with the fuel gas network optimization during the loading mode. The optimization of fuel gas network during holding mode can be seen in our previous work [1] where the detail of the fuel gas network was described. The proposed model was implemented in GAMS 22.7 and solved using BARON 7.5 on a Dell Optiplex GX620 with Pentium IV HT 3 GHz processor and 2 GB RAM.

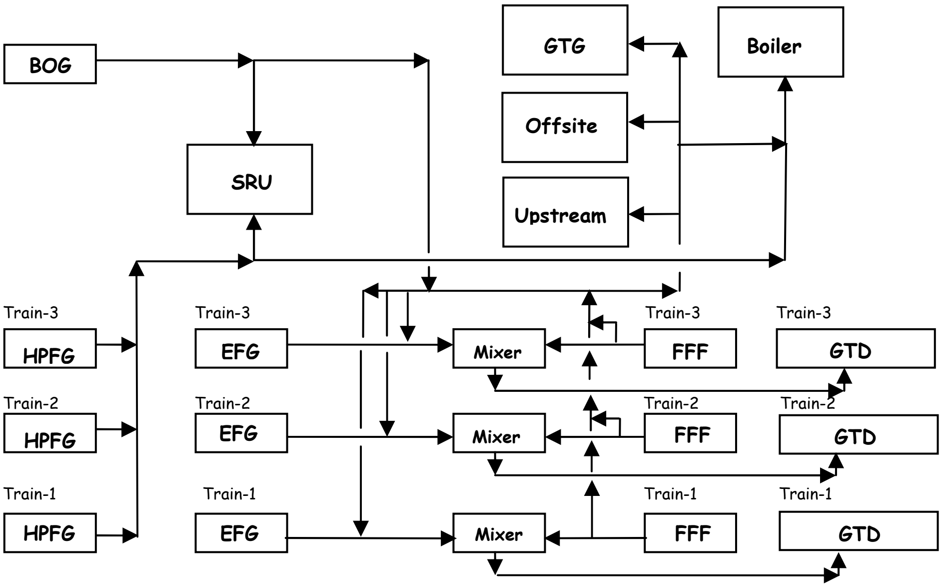

Fig. 2. Existing fuel gas network

BOG, EFG, and HPFG usage correspond to production losses and hence are tail gases. They are expected to be fully consumed by the fuel gas system. On the other hand, FFF usage is only to fill the gap between the plant power requirements and the amount of power which can be extracted from the other three sources. FFF is undesirable source of fuel since increasing FFF usage decreases the amount of feed gas flowing to the main cryogenic heat exchanger (MCHE) causing reduced LNG production. Therefore, FFF consumption should be minimized. In addition, we consider an additional fuel source in the form of jetty BOG which is vapors generated during the loading of LNG into delivery ships. Hence, it is not produced continuously. For the purpose of this study, we use the average jetty BOG rate throughout the year which is a deterministic value based on the ship arrival schedule.

In this case, we combine fuel sources and sinks which have identical characteristics. Hence, similar fuel sources/sinks from different trains are lumped into a single fuel source/sink. The comparison between the fuel gas consumption before and after jetty BOG integration is shown in Table 1. It is shown that by integrating jetty BOG as additional fuel, the FFF consumption decreases by about 15% overall. This reduction increases the plant efficiency by reducing the use of FFF.

Table 1. Fuel consumption before and after jetty BOG integration (flow unit)

Fuel source	Before	After
FFF	53.62	45.77
Jetty BOG	0	50.21

5. Conclusion

We showed that our superstructure and MINLP for fuel gas network are efficient and practically useful. Our approach is able to globally optimize the fuel gas network synthesis problem for both grass-root and retrofit purposes. We showed using industrial case study that our methodology can integrate the available jetty BOG to reduce the consumption of FFF.

Acknowledgements

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