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Energy efficient process structure design of LNG/NGL recovery for offshore FLNG plant

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Abstract

FLNG are the floating NG processing plant deployed in the remote marine environment. Their design criterions are different form onshore plant in terms of process safety, storage, compactness, flexibility and simplicity of operation. Considering the FLNG requirements an integrated approach for NG liquefaction and HC recovery is presented. The liquefaction of NG is carried out using commercially tested SMR process and heavier HC are recovered using energy efficient distillation scheme. The main integration highlights between NG liquefaction and recovery modules are the common refrigeration utility and warm feed splitting between two modules. Once the preliminary integrated design is obtained there remain several optimizing parameters that increases the plant efficiency thus, optimization is carried out using process knowledge and modified coordinate decent methodology. Compared to the preliminary design the optimization results show significant energy savings of about 30% in compression energy demand and 20% in columns reboiler duty demand. Conclusively the overall comparison of preliminary and optimized design is made for the given capacity and general recommendations for FLNG design improvement are proposed.

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Keywords: NGL, LNG, liquefaction, Optimization, Simulation

1. Introduction

Population and income growth are the key drivers behind the growing world energy demand. By the year 2030 the world population is projected to grow by 8.3billion, which means an additional 1.3 billion people will need energy. World's energy consumption is projected to increase by 56% between 2010 and 2014 [1]. Hence to sustain the economic growth needs a continuous surge of energy. Depleting crude oil reserves, growing environmental concern and intense competition in the global market pave the way for clean energy sources like NG. NG is the fastest growing fossil fuel and increases at 1.7% p.a, its usage is seeping in every sector of human society ranging from; basic house hold heating, manufacturing industry,

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transportation sector, electricity generation etc. However the problem with NG is that it is often found at remote locations and to bring it to the world market require liquefaction which is energy intensive and entails as much as 30% of the total energy in NG value chain. Heavier HC removal is also energy demanding step in NG value chain and holds great economic benefits in terms of valuable products obtained like propane, butane, and others that are often sold in their respective markets.

The enthusiasm of exploiting offshore reserves coupled with the rapid changes in NG market put the emphasis in NG market on integration of LNG and NGL technologies in single floating facility called FLNG. Their design criterions are different form onshore plant in terms of process safety, storage, compactness, flexibility and simplicity of operation. Considering these requirements an integrated approach for NG liquefaction and HC recovery is presented. The integrated design comprised of several sub-optimal parameters that were optimized using process knowledge and modified coordinate decent methodology. The proposed integrated FLNG design performs better in terms of energy and space requirements thus suitable for mid-sized offshore plant operations.

Nomenclature

NG	Natural gas	FLNG	Floating Liquefied Natural gas
HC	Hydrocarbons	SMR	Single Mixed Refrigerant
LNG	Liquefied natural gas	LPG	Liquefied petroleum gas

2. Proposed Integrated LNG/NGL Scheme

The integrated scheme of LNG and NGL recovery is shown in Fig 1. There are several commercial schemes for NG liquefaction nevertheless SMR process is considered most energy efficient based on specific energy and equipment count. Its simple design and ease of operation with small foot-prints make it cost effective for offshore NG field development [2]. Thus, SMR is used for NG liquefaction in the integrated scheme. Fig 1 illustrates the SMR cycle with a single loop of refrigerant mixture where MR is compressed cooled in plurality of compression stages. The precooled feed in sent to the high pressure methane scrubber and the bottoms are sent to the heavier recovery scheme. A portion of recovered methane from scrubber is directed for cooling in cryogenic assembly and later used as cold reflux stream in scrubber (see Fig 1) while the remaining is subcooled to LNG. The cold methane reflux stream increases the process efficiency and reduces the heavier components in the scrubber overhead to minimum moreover the generation of cold utility for methane scrubber is not required. The bottom stream from the scrubber is sent to the heavier separation train (see Fig 1). The optimized configuration of heavier separation train recovered ethane, propane and butane. Ethane can be either rejected in LNG or sold separately depending on its demand. In the last column (LPG) of heavier separation train cooling water was used as the cooling as the condensing medium that reduced the operating cost to further minimum

3. Optimization scheme for integrated LNG/NGL facility

The liquefaction efficiency in SMR process strongly depends on the refrigerant compositions and its operating pressures. The non-optimal execution of these variables contributes to the process irreversibility. In the heavier recovery sequence reboiler duty is the main operating cost and depends on several factors like column number of trays, feed tray location, reflux ratio. Considering the main energy demand the decrease in compression and reboiler energy demand in LNG/NGL sequences are considered as optimization objective and with the help of optimization algorithms[3] described in Fig 2 both sequences are optimized.

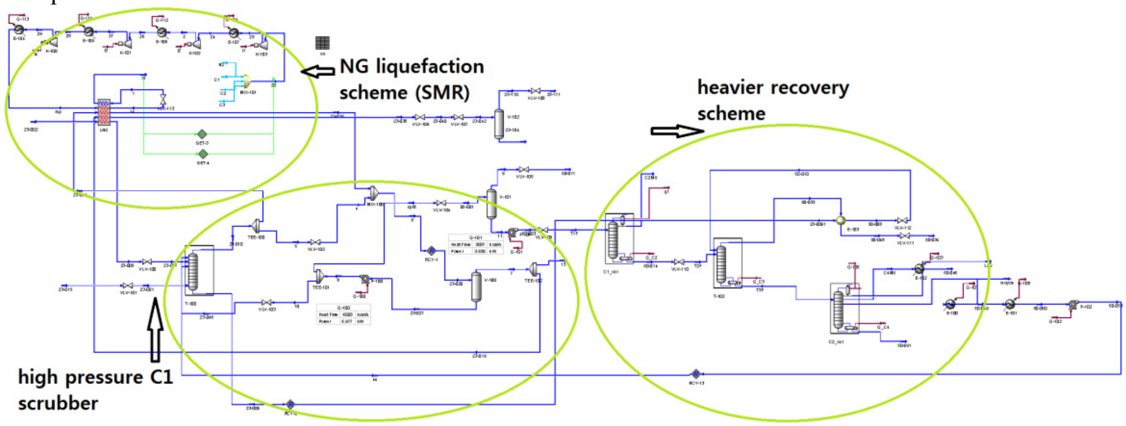
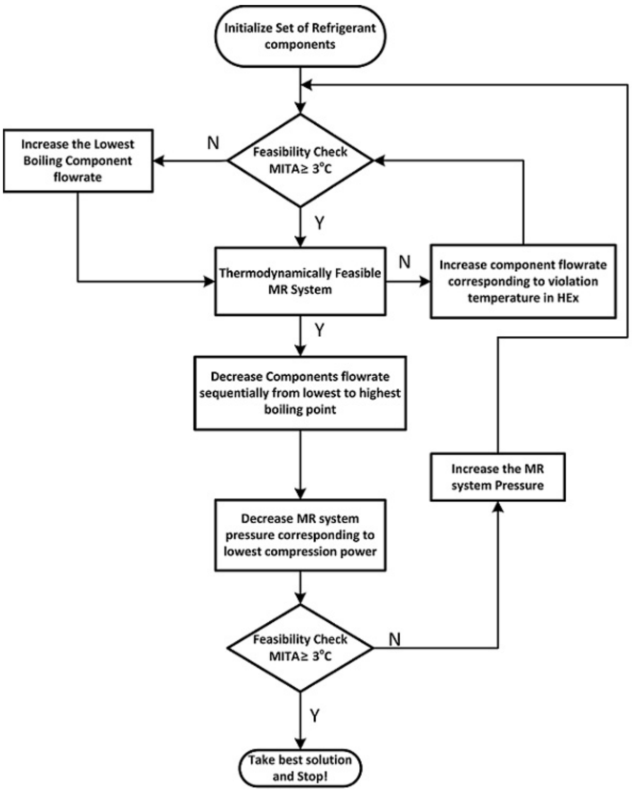


Fig 1. Proposed LNG/NGL integrated scheme for FLNG



Step 1. Generate a random starting point $X_0 = \{x_1, x_2 \ldots x_n\}^T$ within the variable bounds and set $F_{\min} = f(X_0)$.

Step 2. To find the search direction, an exploratory search around X_0 as the base point is performed, which starts with polling: for $k = 0, 1, \ldots\ldots$

If $f(t) < f(x_k)$ for some $t \in P_k := \{x_k \pm \Delta_k e_i : i \in n\}$, then set $x_{k+1} = t$ and $\Delta_{k+1} = \Delta_k$; otherwise x_k is the minimum over the set P_k.

Step 3. Set $x_{k+1} = x_k$ and $\Delta_{k+1} = \frac{\Delta_k}{2}$ and repeat Step2, if no improved solution is obtained then go to Step 1 and begin with a new random solution.

Step 4. Starting from the solution obtained in Step 3, the univariate search is performed from first coordinate, holding others fixed to the value obtained in Step 3. The i^{th} coordinate of x_i^{k+1} is: $x_i^{k+1} = \arg\min f_{y \in R}(x_i^{k+1}, ---, x_{i-1}^{k+1}, y, x_{i+1}^{k}, ---, x_n^{k})$

Step 5. A cyclical iteration is performed through each coordinate and the new solution is updated from the previous candidate solution $F(X_0) \geq F(X_1)$

Step 6. Assuming X_1 as the new starting point, repeat Step 4 and 5 within the space created around $0.1X_1$ using $0.01\Delta_k$ as the step size for implementing a box search and obtaining the local optimum solution $X_1^{'}$.

Step 7. Randomize the first coordinate of $X_1^{'}(rand, 2, 3, \ldots n)$ and repeat Steps 4 to 6 obtaining $X_2^{'}$, again randomize the second coordinate of $X_2^{'}(1, rand, 3, \ldots n)$ and perform Steps 5 to 7.

Step 8. Follow Step 7 for all coordinates and repeat Steps 4 to 7 and obtain an array of local optimal solutions.

Step 9. Terminate when the defined number of repetitive results within the used function tolerance $|fx_i - fx_{i-1}| < FunTol$ is obtained, otherwise go to Step 4.

Figure 2. Knowledge based and modified coordinate decent algorithm for LNG/NGL steps optimization.

4. Optimization results

The optimization results from coordinate decent and knowledge inspired algorithm represent compression energy savings of about 30% compared to the preliminary design (base case). Table 1 illustrates the optimization results for LNG/NGL. The optimization results in 30% and 20% objective improvement.

Table 1. Optimization results of LNG and NGL sequence

Property	Base case	Optimized Case
Liquefaction Step		
Specific power requirement(kW/kg LNG)	$6.18x10^5$	$4.32\ x10^5$
Heavier Recovery step		
Reboiler Duty	9614.50	7907.90

5. Conclusions

The integrated process design of LNG/NGL is proposed for FLNG. The integration highlights include common refrigeration utility and feed splitting. Furthermore the proposed integrated design was optimized with modified coordinate decent methodology and process specific knowledge. The optimization yields significant improvements in compression energy demand and reboiler duty. The optimization methodology is simple and robust, and gives practically applicable results. Conclusively the overall efficiency of the integrated facility is higher than individual standalone facilities.

Acknowledgements

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Biography

Mohd Shariq Khan is Phd in chemical engineering from Yeungnam University South Korea. His research interests include natural gas process plant optimization with stochastic, deterministic and heuristics approaches.

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