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Application of Computer Simulation Technology in Liquefied Natural Gas Process

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In this paper, this paper adopts the sequential modular approach to stimulate the process of natural gas propane precooling mixed refrigerant liquefied natural gas through the computer. The process flow of propane precooled mixed refrigerant liquefied natural gas is analyzed and the impact of methane content in the feed gas on the process flow is calculated. In view of the high energy consumption in the process of propane precooled mixed refrigerant, the optimization model for the liquefaction process is established and the pinch point technology is used to optimize and analyze the liquefaction process taking the minimum sum of the compressor energy consumption and the propane precooling amount as the objective function. After the optimizing calculation, 4.36KJ energy can be saved for the production of unit flow of LNG.

1. Introduction

Natural gas is a kind of clean energy. In recent years, the global liquefied natural gas technology has been further developed. In order to achieve a further reduction in production costs, it is necessary to deal with the energy consumption in the production process (Xiong et al., 2015; Khan et al., 2015). From the perspective of the production system, not only the energy consumption generated by a single device should be considered, such as the heat transfer of enhanced heat exchanger, but also the systematic energy conservation should be constantly optimized from the overall perspective. Therefore, in order to achieve the minimization of the production cost, the production system should be regarded as a whole and scientific and rational methods should be adopted to get the optimal arrangement of the production process.

In the liquefaction of natural gas, the propane precooling mixed refrigerant liquefaction process has great advantages, including high liquefaction rate, simple management and low operating costs (Fang et al., 2018; Sotudeh and Mostoufi, 2004; Seo et al., 2009; Morin et al., 2011). This technology is considered by various countries as the development direction of the natural gas liquefaction process and it is also one of the main application methods in various countries (Khan et al., 2016; Diwekar et al., 1990; Raghunathan et al., 2004). Since the entire process will involve multiple production facilities and the logistics parameters will change drastically with the production, the thermodynamic simulation of the entire process should be performed (Elia et al., 2015; Lu and Xie, 2016 Wang et al., 2014). Through related simulation and analysis, the inadequacies of the process can be identified and the rapid and stable development of the natural gas liquefaction industry can be promoted based on the further optimization of these issues.

2. Simulation of propane precooling mixed refrigerant liquefied natural gas process

2.1 Flow chart of propane precooling mixed refrigerant liquefaction

The process is shown in Fig. 1 and it can be seen that the entire process mainly includes three parts, namely mixed refrigerant cycle, propane precooling cycle and natural gas liquefaction loop. In the whole process, the mainly function of the second part is to precool the mixed refrigerant and natural gas and the first part is used for cryogenic liquefied natural gas.

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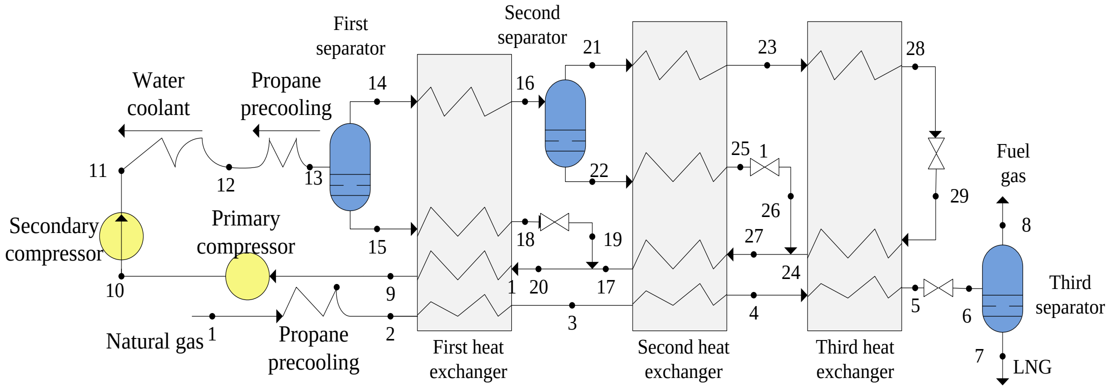


Figure 1: Flow chart of liquefaction of propane precooled refrigerant mixture

It can be seen from Fig. 1 that the equipment will be operated in high pressure. In the first step, the cooling process is conducted with water, allowing for the loss of part of the heat. Then, the propane precooling cycle is used for the precooling. After the process is completed, it will enter the gas-liquid separator to allow the substance to convert into a liquid phase and a gas phase. After the liquid phase is cooled in the first heat exchanger, it will undergo a series of processes such as throttling and cooling and then it will be mixed with the mixed refrigerant, thereby providing the corresponding device with the required cooling capacity. And then, the cooling can be conducted on the separated gas phase and liquid phase. After the gas phase is cooled in the device, it enters a specific vessel for separation and then it will be separated into gas phase and liquid phase. After the liquid phase is cooled in the device, it will undergo throttling, cooling and depressurization. Then, it is mixed with the mixed refrigerant to provide the second device with the required cooling capacity. Then, the cooling is conducted on the separated gas phase and liquid phase. When the gas phase is cooled in the third device, it will undergo throttling and cooling. Then, this object will then enter the third device to cool the natural gas and gas phase mixed refrigerant.

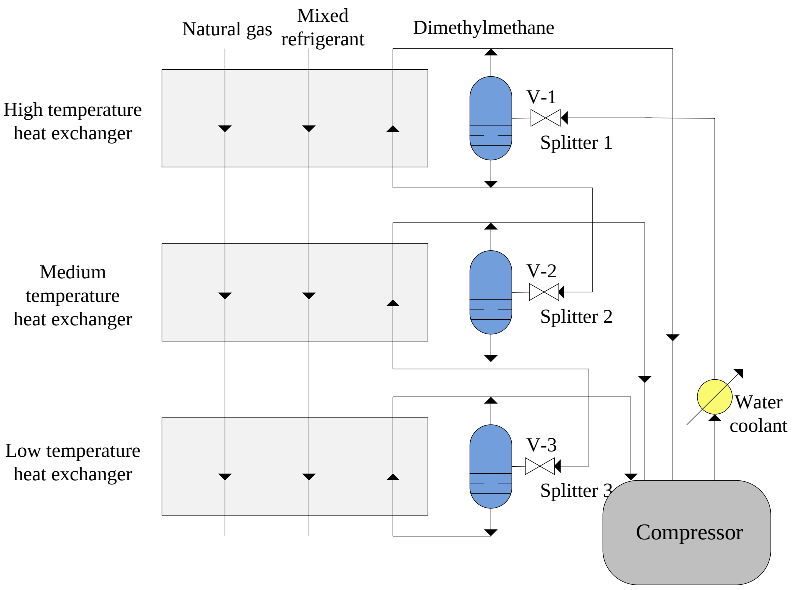


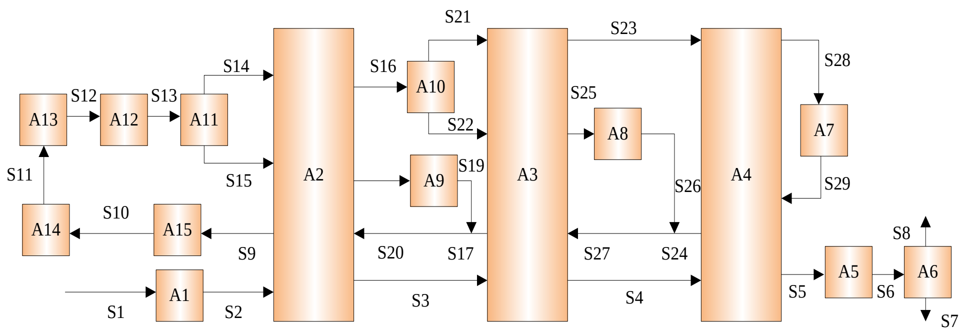
Figure 2: Propane precooling circulation flow chart

The propane precooling cycle is shown in Fig. 2, propane will provide the cooling capacity for the corresponding material through various heat exchangers. The propane will be further processed to enter a high temperature and pressure state and then it will be cooled. At the same time, the object will reduce its temperature and pressure by the throttle valve and then it will be processed by the corresponding device into liquid phase and gas phase. When the gas phase is returned to the designated device, the liquid phase will be

divided into two parts. The role of the first part is the complementary cooling of natural gas and refrigerant and the other part will be saved as refrigerant to facilitate the use of subsequent work.
In the course of the process, the natural gas will be precooled first and then cooled by different devices. Finally, it is depressurized by the throttle valve, which will enable LNG to be stored for a long time under normal pressure.

2.2 Simulation calculation of propane precooling mixed refrigerant liquefaction process

This paper uses the above process as the production core and the detailed information is shown in Fig. 3.



A1,A12-Propane precooling cyclic process;A2-First heat exchanger;A3-Secondary heat exchanger;A4-Third heat exchanger;A5-Throttle 4;A6-Third separator;A7-Throttle3;A8-Throttle 2;A9-Throttle 1;A10-Secondary separator;A11- First Separator;A13-Water cooler;A14-Secondary compressor;A15-Primary compressor

Figure 3: Flow chart of propane precooled mixed refrigerant refrigeration liquefaction

The simulation process can be seen from the following:
In the simulation calculation, calculation should be carried out according to different cycles. The process is divided into two part. The first part is two circulation loops and the other part is the natural gas liquefaction process.
In the process of simulating the whole process through the sequential modular method, since there will be various circulating streams in the process, this method cannot be applied directly. The process needs to be divided into three parts, which are natural gas liquefaction process, mixed refrigerant cycle process and propane precooling cycle. The S_{20}-T, S_4-T are set as the convergence variables and it is necessary to achieve the solution in iterative algorithm by the corresponding algorithm.
(1) Calculation of Mixed Refrigerant Cycle
The flow of natural gas and mixed refrigerant, energy consumption of the equipment and the corresponding end-face parameters of the corresponding device can be obtained using this calculation method.
1 Input the physical properties and related parameters of the corresponding substance.
2 Calculate the actual flow of natural gas.
The end of the entire process is used to carry out the calculation. There are two main devices in the tail end, which are the throttle valve and the separator. The specific information is shown in Fig. 4.

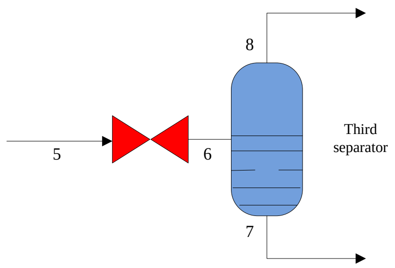


Figure 4: Flow chart of natural gas liquefaction

Existing parameters: the pressure P_5 of node 5, the molar fraction Z_{5t} of the component;
The pressure P_6 of node 6, the molar fraction Z_{6t} of the component;
The flow q_7 of node 7.

In addition, a hidden factor also needs to be considered that the entire separation process of natural gas will be in the isothermal-isobaric state, so the corresponding temperature and pressure of nodes 6, 7 and 8 are all at the same level.
The formula is as follows
a. Set the flow parameter of node 6 equal to 1 mol and call the corresponding module to calculate the flow q_{6L} of node 6.
b. According to formula $\frac{q_6}{1}=\frac{q_7}{q_6L}$, it can be obtained that $q_6=\frac{q_7}{q_6L}$
c. Since the relevant parameter of node 6 has already been calculated, other parameters of node 6 can be calculated through the corresponding module, including temperature and liquid phase molar fraction.
d. From the perspective of the separator itself, there are a total of three logistics connected to the device. The thermal parameter corresponding to the node has already been obtained and the entire separation process of natural gas is in the isothermal-isobaric state, so all parameters can be obtained through the calculation by corresponding modules
e. From the perspective of the throttle valve, the corresponding logistics flow at both ends is at the same level and the expression is q5=q=; and because the whole is the equal baking process, the expression H5=H6 can be obtained
f. Through the obtained parameter pressure and enthalpy value, the temperature corresponding to the node can be calculated;
g. According to the obtained node parameter, other parameters of the node can be calculated through the corresponding calculation method.

2.3 The impact of natural gas composition on process performance

If the methane content contained in the natural gas increases significantly, the low-boiling components also increase, so that natural gas will not liquefy under normal storage conditions. Therefore, under the given conditions, the increase in fuel gas will lead to a substantial increase in the total amount of feed gas. When there is no significant change in other components of the natural gas, the methane content will increase. After the consumption of methane content, the enthalpy value of the natural gas will also increase to some extent. As the methane content continues to increase, the flow of natural gas will also increase significantly. It is precisely because of the above factors that the entropy value of natural gas increases continuously.
It can be seen through the above analysis that if it is intended to generate the same amount of LNG with the increase of methane content, the required cooling capacity H_2-H_7-H_8 will also increase. At this time, the enthalpy value H_9-H_{13} of the corresponding device will remain at a stable level.
The enthalpy value of the unit flow at node 9, 11 and 12 will not be affected by the change of the natural gas composition, so the shrinkage consumption power h_{11}-h_9 will maintain the established level and the required cooling capacity h_{11}-h_{12} will also remain unchanged. If the flow increases, the total value of the device and the cooling capacity will also increase.
The increase in the methane content will lead to the increase in nodes H_1 and H_2. However, the corresponding temperature of the node is significantly lower than the node, its growth will not be too significant. However, in the refrigerant loop, the refrigerant flow increases significantly, so the precooling capacity of the corresponding device also increases. After this, the methane content also increases and the propane precooling capacity will also increase to some extent.
With the increase of refrigerant flow, the amount of liquid obtained through the first device will also increase to a certain extent.
Q_{ml}- cooling capacity produced by low pressure mixed refrigerant,
Q_{mg}- consumed cooling capacity of methane by MRC,
Q_p- cooling capacity produced by propane precooling cycle,
W_m- Compressor power consumption on MRC,
W_p- Compressor power consumption on propane precooling cycle

3. Optimization of propane precooling mixed refrigerant liquefaction process

The liquefaction process is regarded as a heat exchanger network for the optimization. The most scientific and reasonable choice can be found with simple calculation. In the entire process, the combination of different devices can form a heat exchange network. For this process, the author takes the minimization of energy consumption as the research objective and finds the minimum allowable heat transfer temperature difference of the heat exchanger network. After the determination of relevant parameters, the minimum utility engineering load can be obtained through the question table algorithm and then the adjustment of the heat exchanger network can be performed. Throughout the production process, there will be a variety of cold and hot logistics. Therefore, the question table method tis used for the corresponding calculation.

3.1 Process logistics parameters

According to relevant principles, whatever involves the conversion process will be extracted and will be analyzed as a whole, as is shown in Fig. 1, extracting all process logistics that match the heat transfer of process logistics or match the heat transfer of utility engineering logistics as the logistics participating in the energy analysis. The basic data of process logistics is shown in Tab. 1.

Table 1: Basic data of process logistics

Material flow	Starting point pressure (MPa)	Terminal pressure (MPa)	Starting point temperatureT(K)	Final temperatureT(K)	q(mol)
1-2	4.5	4.5	293.0	214.0	1.193
2-3	4.5	4.5	214.0	179.5	1.193
3-4	4.5	4.5	179.5	163.2	1.193
4-5	4.5	4.5	163.2	143.0	1.193
11-12	2.80	2.80	360.0	300.2	0.910
12-13	2.80	2.80	300.2	214.0	0.910
14-16	2.80	2.80	214.0	190.5	0.380
15-18	2.80	2.80	214.0	190.5	0.530
20-9	0.32	0.32	168.5	214.0	0.910
21-23	2.80	2.80	190.5	185.4	0.180
22-25	2.80	2.80	190.5	161.2	0.200
23-28	2.80	2.80	185.4	143.0	0.180
27-17	0.32	0.32	138.9	190.5	0.380
29-24	0.32	0.32	121.3	157.6	0.180

3.2 Pinch Analysis of Liquefaction Process

Although the location of the pinch can be quickly found by the temperature-baking method, this method also has certain deficiencies. That is, errors are likely to occur when calculating the thermal load and at the same time, it is difficult to complete the automatic calculation work. Therefore, the question table method is used to determine relevant parameters.

(1) Set the minimum heat transfer temperature difference as ΔT_{min};

The temperature difference corresponding to the heat flow is 15.4K

Then the corresponding temperature difference of the cold logistics is 14.6K

It can be inferred that ΔT_{min} is 30K

(2) Divide the sub-network and perform heat balance

This temperature should exceed the cold logistics ΔT_{min}, so that it can be ensured that the established index of the object will not be lower than ΔT_{min}.

$$O_k = I_k - D_k \tag{1}$$

$$D_k = (\sum C_{pc} - \sum C_{ph})(T_k - T_{k+1}) \tag{2}$$

In the above expression, Dk refers to the K subnetwork deficit

Ik refers to the heat of the K sub-network input by the outside and its unit is kW;

Ok refers to the output heat corresponding to the K subnetwork and its unit is kW;

$\sum C_{pc}$, $\sum C_{ph}$ are the inlet temperature and outlet temperature corresponding to the temperature zone and the unit is °C;

k refers to the subnetwork number.

According to the above content, the parameters can be compared and the specific information is shown in Tab. 2.

Attention: Wc——Wasted work of compressor， kJ；

Qp——Amount of propane precooling， kJ.

According to Tab. 2, after a series of optimization, the LNG of the flow can effectively reduce by 4.36KJ; the water cooling capacity will increase slightly and the liquefaction rate will also decrease to some extent. If the energy consumption analysis can be separated, it can be known that the reduction in the compressor energy consumption will be significantly smaller than that in the propane precooling capacity.

Table 2: Comparison charts before and after process optimization

Performance parameter	Before the optimization	After the optimization
W_c， kJ	8.54	7.98
Q_p， kJ	30.67	26.87
$W_{c+} Q_p$， kJ	39.21	34.85
Refrigerant mass flow rate ，mol	1.523	1.824
Amount of water cooling， kJ	3.65	4.80
Liquefaction ratio， %	84.1	83.8

4. Conclusion

(1) This paper adopts the sequential modular approach to stimulate the process of natural gas propane precooling mixed refrigerant liquefied natural gas through the computer.
(2) This paper analyzes the impact of the composition ratio of the feed gas on the process. With the increase in methane content, the compressor power consumption, refrigerant flow and propane precooling capacity all increase.
(3) The minimum sum of compressor energy consumption and propane precooling capacity is taken as the objective function and the pinch point technology is used to optimize the LNG process. After the optimizing calculation, 4.36KJ energy can be saved for the production of unit flow of LNG.

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