Simulation of a novel single-column cryogenic air separation process using LNG cold energy

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Background

Future efficiency improvement of LNG cold energy integrated with air separation process (ASP) for large-scale LNG receiving terminal station calls for revolutionary development of distillation system as well as the LNG thermal recovery system (LTRS). Novel cryogenic ASP utilizing heat pump distillation technology can save up more than 30% power consumption than conventional process, while no researchers has attempted to combine it with a high efficiency LNG thermal recovery system.

Present works

- Verification and optimization work of the proposed novel single-column cryogenic ASP using LNG cold energy on the Aspen Hysys® simulation platform.
- Comparison work of the proposed process with the simulation results from the latest literatures.

Conclusions

- A novel atmospheric single-column ASP utilizing heat pump technology and LNG cold energy is proposed.
- Simulation results shows that the cyclic nitrogen flow rate and maximum pressure of cyclic nitrogen is the vital factors for LNG thermal recovery system (LTRS) and their optimal value is 1.82 MPa and 50,000 Nm^3/h, respectively.
- The proposed process provides with standard liquid products of nitrogen (99.999%) and oxygen (99.8%) at 14,287 Nm^3/h and 10,250 Nm^3/h, respectively.
- Power consumption per unit mass of liquid product N_{LIQ} is 0.218 kWh/kg, and the total exergy efficiency η_{ex} of the system is 0.575, which is 30% higher and 13.4% lower than those of the traditional process, respectively.
- To further improve the power efficiency of the LTRS, the design of system with elevated LNG pressure may be the solution.

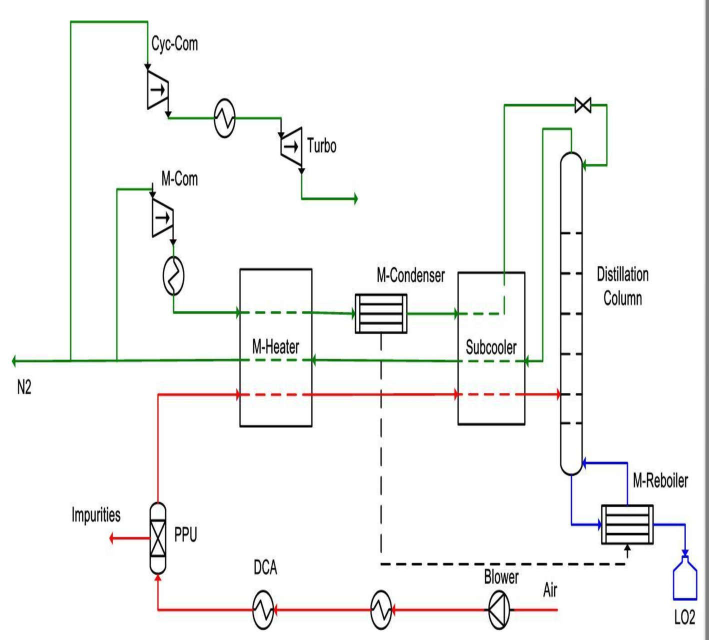
Process design

Heat pump Distillation

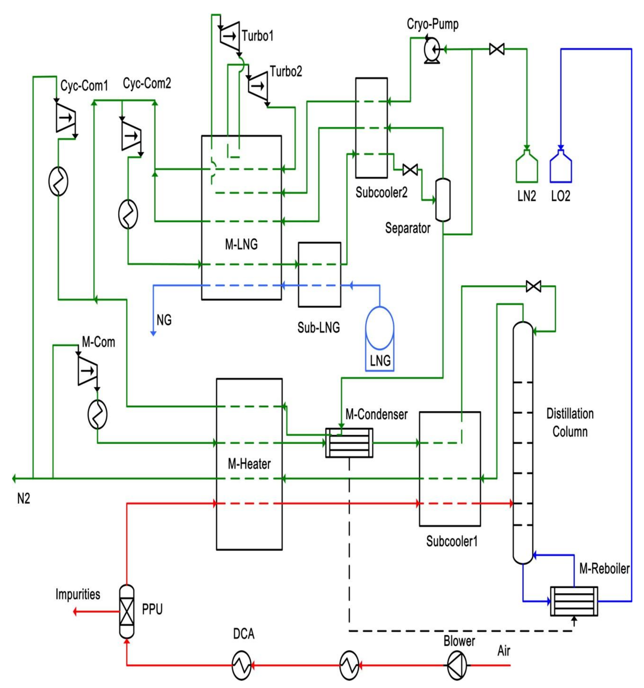
The key feature is the substitution of a nitrogen compressor for the traditional air compressor which dramatically decreases the operation pressure of the distillation column

Traditional double-column is substituted by a single column since the two columns have the same pressure.

An additional refrigeration cycle is used to maintain reasonable temperature differences in the multi-stream heat exchangers as well as make up cold energy deficit



Process Flowsheet



LNG cold energy recycling heat exchanger system main features :

- Nitrogen, as an inert gas readily accessible in air separation industry, is chosen as the cyclic medium;
- Recycled gas is not introduced into the distillation column system, and the liquid nitrogen is generated in LNG recycling system;
- Cryogenic pumps and turbo expanders are used to make up the refrigeration deficit as well as maintain a proper temperature difference between the LNG refrigerant and incoming cyclic nitrogen.

Simulations

Operational Conditions

•Feed air inlet conditions:
50,000 Nm^3/h; 298.15 K;1 atm; ideal gas mixture of 79.1%N_2+20.9%O_2 by volume
•Efficient of the equipment:
Feed air & nitrogen compressor isentropic efficiency 0.8
Turbine isentropic efficiency 0.75
cryogenic pump efficiency 0.75
mechanical efficiency 0.95
•Heat exchanger setting:
The minimum temperature difference 1.5 K ; 1 K (Sub-LNG)
•Desired productivity:
Liquid nitrogen(99.999%);liquid oxygen (99.8%)
•The cold energy loss rate:
20 kW

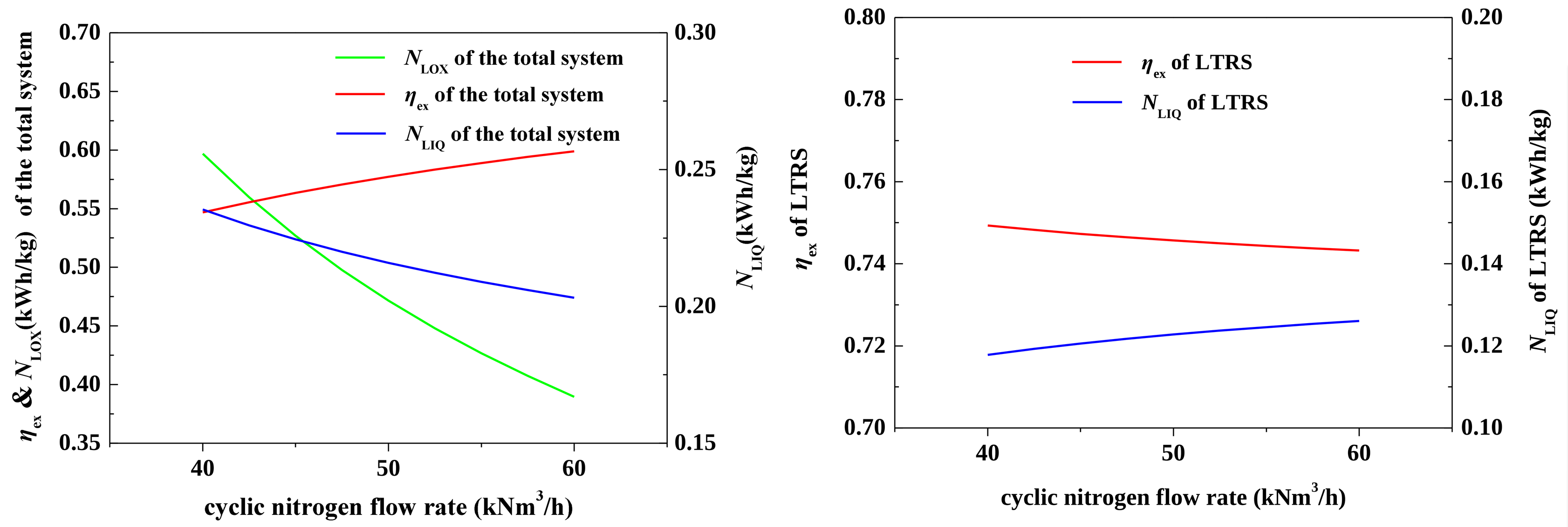
Distillation Column Operational Conditions

The distillation system is the vital part of the entire system, a lot of attentions have been put on the optimization of the distillation column, due to limitations of space, this part of work will not be discussed in this paper, and some of the important operation parameters are listed in Table below.

Number of stages	feedstock					Reflux Nm^3/h	Reflux ratio	Liquid oxygen Nm^3/h	Liquid nitrogen Nm^3/h
	Type of feedstock	Position of feedstock	Flow rate Nm^3/h	Quality of feed air	P/MPa				
60	air	30	50000	0.99	0.12	31950	1.58	10250	14287

Results

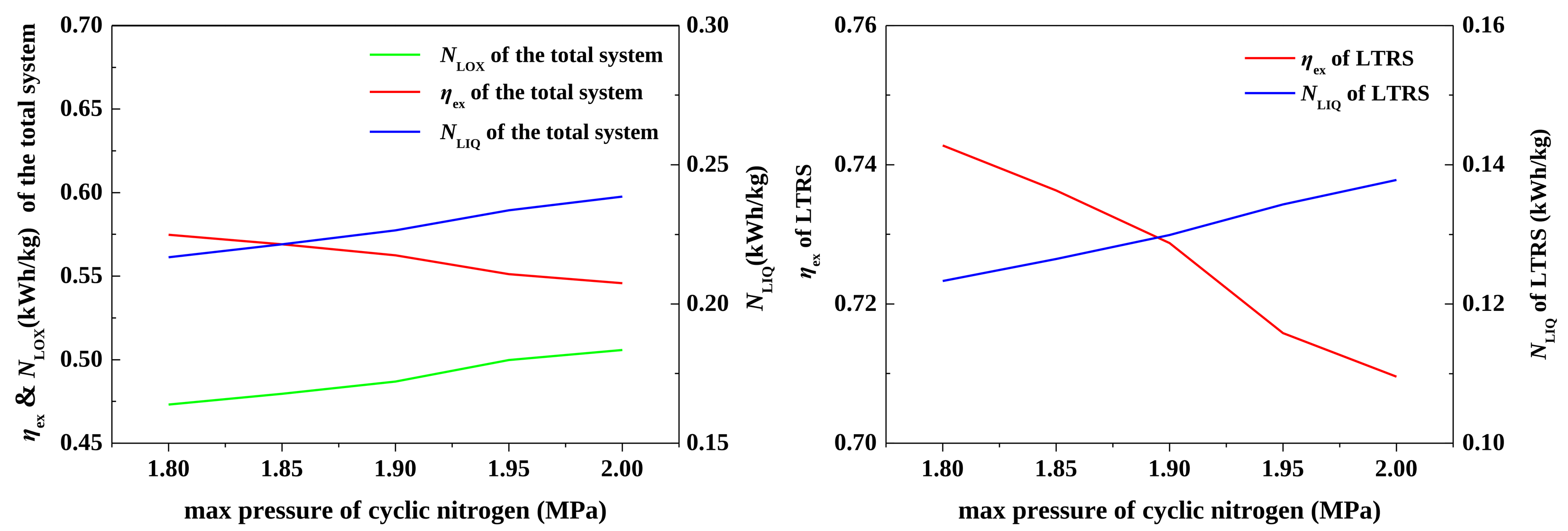
Variation Characteristics of Total System & LNG Heat-exchanger System



The systematic performance varied with the cyclic nitrogen flow rate

The power consumption per unit mass of liquid product N_{LIQ} and power consumption per unit mass of liquid oxygen N_{LOX} decreases greatly as the cyclic nitrogen flow rate changing from 40 to 60 kNm^3/h. Correspondingly, the total exergy efficiency increases in this process.

The performance of the LTRS is less influenced by the cyclic nitrogen flow rate as the exergy efficiency η_{ex} and N_{LIQ} of LTRS and is slightly decreased and increased with the changing of the flow rate, respectively.



The systematic performance varied with maximum pressure of cyclic nitrogen

The maximum pressure of cyclic nitrogen is just contrary to the cyclic nitrogen flow rate the way it influence the perform of the entire system as well as the LTRS. The N_{LIQ} and N_{LOX} increases greatly as the maximum pressure of cyclic nitrogen changing from 40 to 60 kNm3/h. And the total exergy efficiency η_{ex} decreases in this process.

The η_{ex} and N_{LIQ} of LTRS is decreased and increased by the amount of 0.02~0.04 with the changing of the maximum pressure of cyclic nitrogen, respectively.

Plant Performance Comparison

The optimal process is simulated and compared with the traditional process 1&2 from literature of Xu et al. (2014)

The proposed process is more efficient in producing liquid product with a power consumption per unit mass of liquid product around 0.218 kWh/kg, which is 30% lower than that in the latest literature. However, the LNG consumption and flow ratio of cyclic nitrogen and processing air is much too greater than the traditional processes, which means a longer start-up time as well as a larger LNG requirement. As a result, the total exergy efficiency η_{ex} is 13.4% lower than the traditional process2.

Technical Specifications	Traditional process1	Traditional process2	Novel process
handling capacity of air/ t h^{-1}	20	20	20
LNG outlet pressure/MPa, Temperature/K	3.0, 300	0.12, 285	0.11, 283
LNG consumption/t h^{-1}	4.98	2.778	4.434
flow ratio of cyclic nitrogen and processing air	0.6875	0.1014	1.0000
compression work of air /kW	1580	641.5	113.6
compression work of nitrogen/kW	462.6	377.6	2029.5
Air pretreatment system power consumption/kW	600	450	142.9
The maximum operating pressure/MPa	2.6	1.5	1.82
Power consumption per unit mass of liquid products/kWh kg^{-1}	0.358	0.313	0.218
Total exergy efficiency/%	38.2	66.4	57.5

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