Dynamic simulation of mixed refrigerant process for small-scale LNG plant (ID:465)

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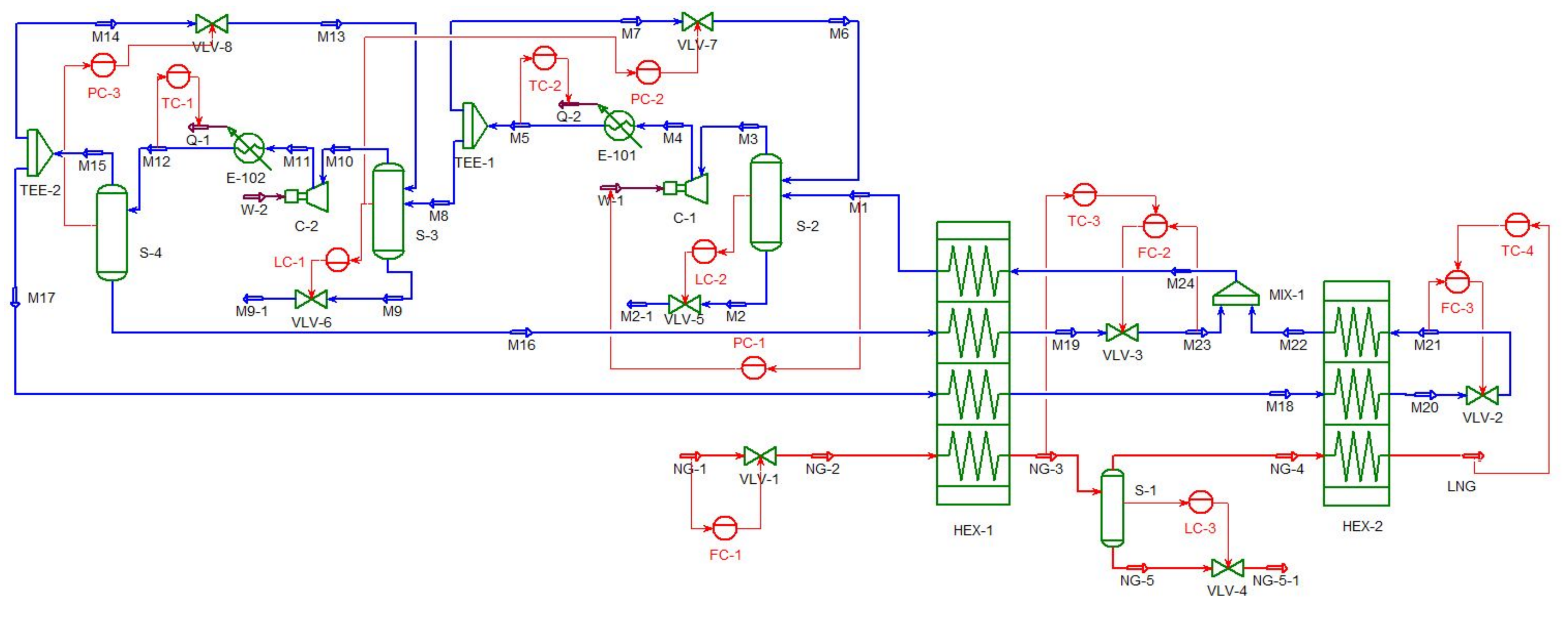
Introduction

Most of optimization studies concentrated on designing mixed refrigerant liquefaction process with lower energy consumption at steady-state simulation. Only a few studies have addressed dynamic simulation of natural gas liquefaction process. The main aim of this study was to conduct a dynamic simulation of mixed refrigerant liquefaction process for small-scale LNG plant and to investigate the dynamic responses of disturbances. The variations of natural gas composition, temperature, pressure, flow rate were adapted as disturbances to test the stability and dynamic responses of the process. The dynamic responses of LNG temperature and total energy consumption were the criteria to investigate the influences of disturbances on the process. Finally, the dynamic responses of disturbances were obtained and discussed.

Process Design



Parameters	Value	
The mole fraction components	CH_4	0.9459
	C_2H_6	0.0343
	C_3H_8	0.0059
	i-C_4H_{10}	0.0010
	n-C_4H_{10}	0.0012
	i-C_5H_{12}	0.0003
	n-C_5H_{12}	0.0003
	C_6H_{14}	0.0005
	N_2	0.0106
	Total	1
Natural gas temperature	40℃	
Natural gas pressure	4.0MPa	
Natural gas flow rate	$5\times10^4 Nm^3/d$ (92.95 kmole/h)	
Temperature after water cooler	40℃	

Degrees of Freedom

$$N_{ss}=N_{MV}-N_0$$

Where N_{MV} is the dynamic manipulated variables; N_0 is the number of degrees of freedom with no steady-state effect

The number of manipulated variables of mixed refrigerant process in this study is 12 (**N_{MV}=12**), the details are shown as follow:

1) One natural gas feed valve (VLV-1)
2) Two throttling valves in mixed refrigerant process (VLV-2, VLV-3)
3) Two heat duties of water coolers (Q-1, Q-2)
4) One compressor speed
5) Two anti-surge valves (VLV-7, VLV-8)
6) Three liquid holdup valves (VLV-4, VLV-5, VLV-6)

The liquid holdups have no steady state effect, so the number of degrees of freedom with no steady state effect is 3 (**N_0=3**).

Control Structure

- The main control objective of small-scale LNG plant is to produce LNG product with specified LNG temperature in a stable and low compressor duty state.
- Feed gas flow rate is controlled by adjusting the opening percentage of VLV-1. (q = 92.95 kmole/h)
- LNG temperature is controlled by adjusting the vapor mixed refrigerant (VMR) flow rate (VLV-2). ($T_{LNG} = -159℃$)
- NG-3 temperature is controlled by adjusting the liquid mixed refrigerant (LMR) flow rate (VLV-3). ($T_{NG-3} = -61.86℃$)

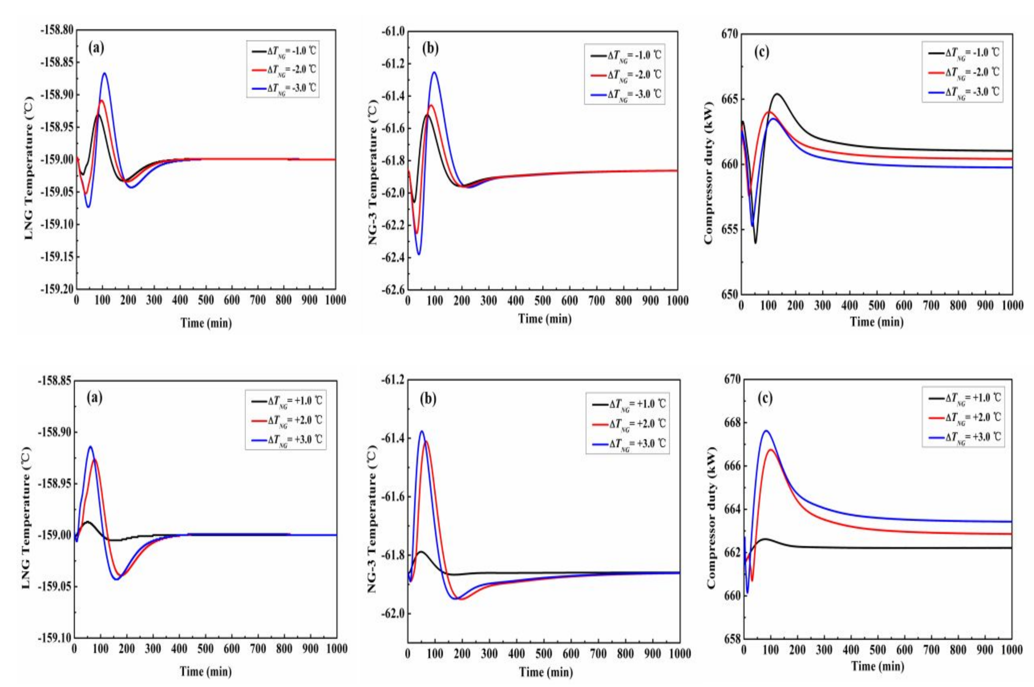
Results and analysis

1.Validation of dynamic results

	Steady-state	Dynamic	Deviation
Feed gas flow rate (kmole/h)	92.95	92.95	0%
Feed gas temperature (℃)	40.00	40.00	0%
Feed gas pressure (kPa)	4000.00	4000.00	0%
LNG temperature (℃)	-159.00	-159.00	0%
NG-3 temperature (℃)	-61.80	-61.86	0.097%
MR flow rate (kmole/h)	265.00	255.00	3.774%
MR compressor suction pressure (kPa)	230.00	235.00	2.128%
MR compressor discharge pressure (kPa)	3300	3322	0.667%
Compressor duty (kW)	672.80	661.6	1.665%

- Dynamic simulation results are verified by comparing with steady-state simulation results.
- Most of the variables in dynamic simulation is within **0-5% deviation** of steady-state simulation.

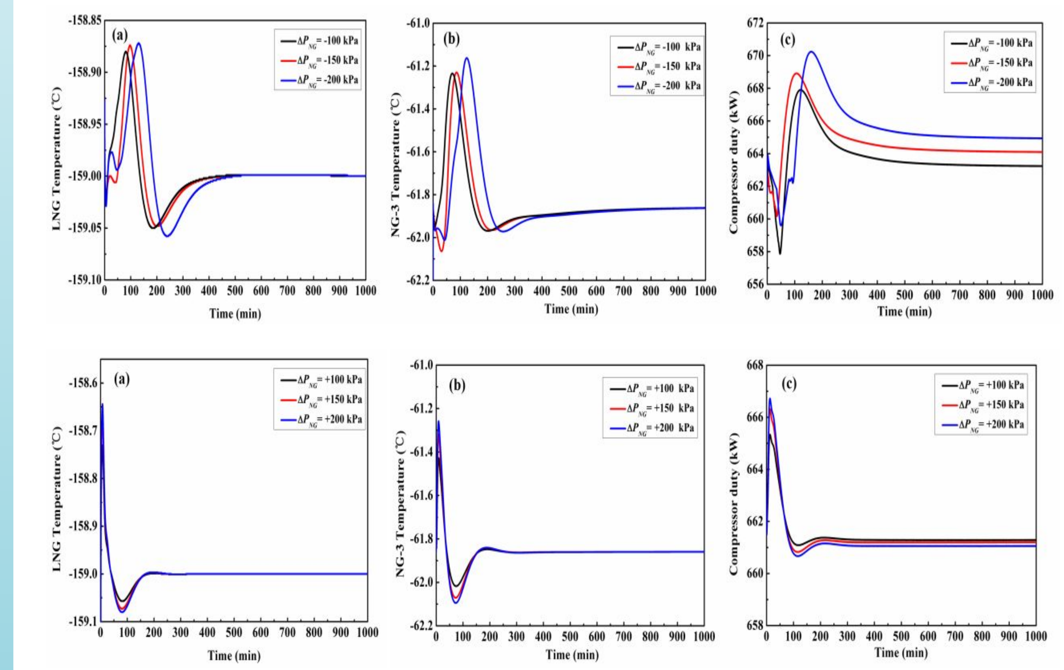
2. Disturbance of feed gas temperature



- The feed gas temperature is varied by 1, 2 and 3℃ downward and upward
- LNG temperature and NG-3 temperature can go back to set point values with 300 mins. The bigger disturbance, the more oscillation.
- Compressor duty will decrease when feed gas temperature decrease and increase when feed gas temperature increase

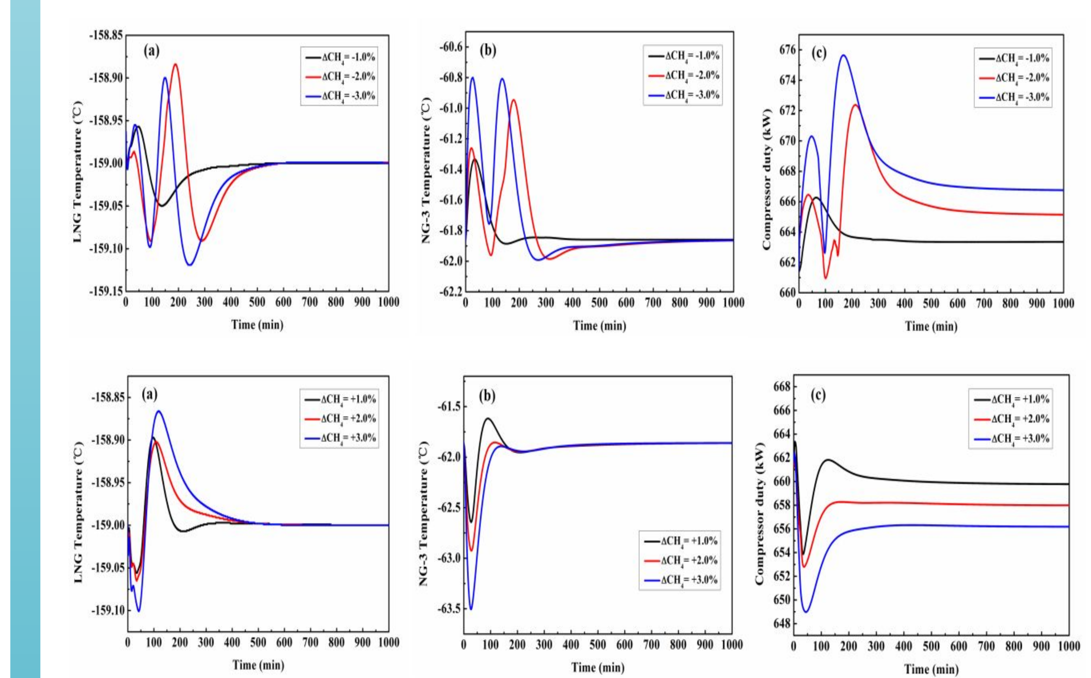
Results and analysis

3. Disturbance of feed gas pressure



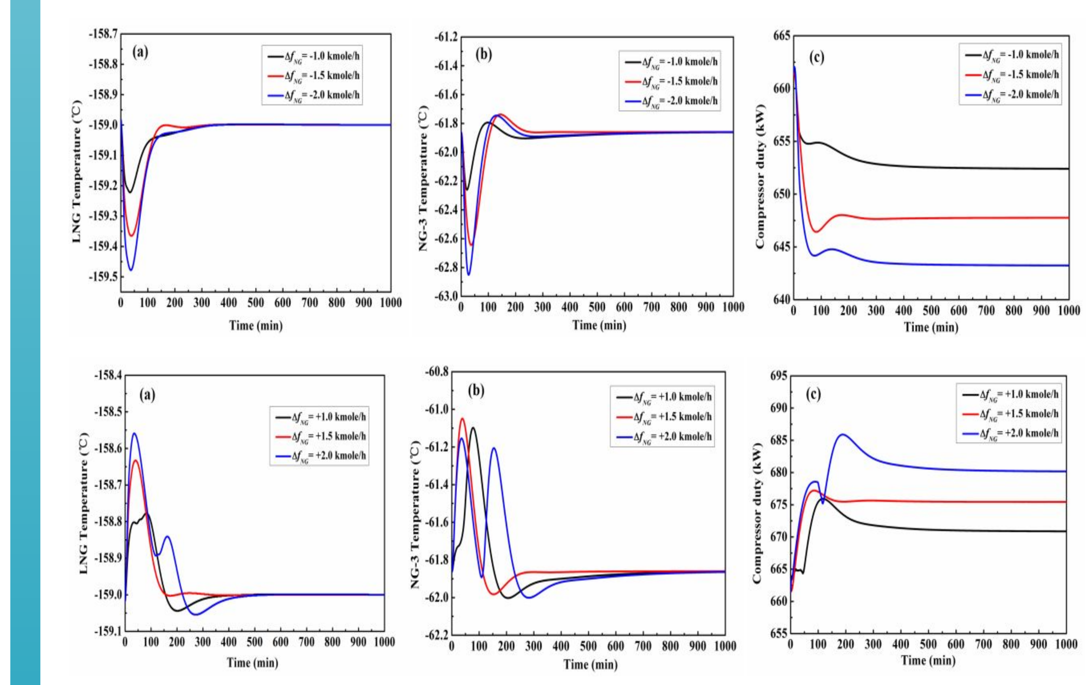
- The feed gas pressure is varied by 100, 200 and 300 kPa downward and upward
- The decrease of feed gas pressure has a bigger influence on the process than the increase of feed gas pressure.
- Compressor duty will decrease when feed gas pressure decrease, while has little change when feed gas pressure increase

4. Disturbance of feed gas composition



- The methane composition is varied by 1%, 2% and 3% downward and upward
- The variation of methane composition can make the process a big oscillation
- The process needs to spend 400 mins to go back to stable state

5. Disturbance of feed gas flow rate



- The feed gas flow rate is varied by 1, 1.5 and 2 kmole/h downward and upward
- The decrease of feed gas flow rate has a smaller influence on the process
- Compressor duty will decrease when feed gas temperature decrease and increase when feed gas temperature increase

Conclusion

1.Dynamic simulation of mixed refrigerant liquefaction process for small-scale LNG plant was developed to investigate the dynamic behaviors.
2.The comparison showed good match between dynamic simulation and steady-state simulation.
3.The results indicated that the process can handle these kinds of disturbance and go back to the specified values after some times.
4.The mixed refrigerant process showed good operation flexibility and can estimate different kinds of disturbance in a wide range.

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