Simulation and Analysis of the Combined Power Process of LNG Cold Energy Recovery for Electricity Production

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Abstract: The model of LNG cold energy recovery consisting of a Brayton cycle and a Rankine cycle is constructed in Aspen Plus. The effects of the inlet and outlet pressure of the turbines, ammonia-water flow rate, condensing temperature and the compressor outlet pressure to the thermal efficiency of the combined power cycle have all been performed sensitivity analysis. The result shows that the thermal efficiency increases with the turbines inlet pressure and the compressor outlet pressure. Meanwhile, decreasing the ammonia-water flow rate and condensing temperature can also achieve such effects.

1 Instruction

With economy rapid development, natural gas[1] will be mainstream energy all over the world. In China, the storage of natural gas (NG) is abundant, but the origin is remote. The NG being liquefied is a convenient way to transport to other places. On the terminal to receive liquefied natural gas (LNG), LNG is pressed by pump, vaporized to gas in heaters, and delivered to users in the end. LNG contains so much cold energy to be recycled during vaporization, and the energy from LNG releases can reach to 830~890kJ/kg. However, when it is regarded as fuel, the LNG cold energy recovery can be used to generate electricity [2], air separation [3], cryogenic grinding [4] and light hydrocarbon separation [5] etc. Making most use of LNG cold energy can't only save energy but also bring considerable economic benefits.

Many scholars have already researched on the combined power cycle. T. Miyazaki and Y.T. Kang [6] et al. have proposed a power cycle by combining waste heat with LNG cold energy and analyzed how ammonia water concentration, the inlet and outlet pressure of turbines and coefficient of heat transfer of condenser influence the combined power cycle. Wang and Li [7] et al. have a new study of the power cycle to recovery LNG cold energy with a low heat source. The result shows that the thermal and exergy efficiency increase as the heat source temperature and the turbine inlet pressure increases and condensing temperature decreases. Manuel Romero Gómez et al. [8] have presented a novel power cycle consisting of a combination of a closed Brayton cycle with a stream Rankine cycle, and analyzed the effects of some key parameters including the temperature at the compressor inlet, the compression ratio, the temperature at the Brayton cycle turbine and the LNG pressure to the cycle performance.

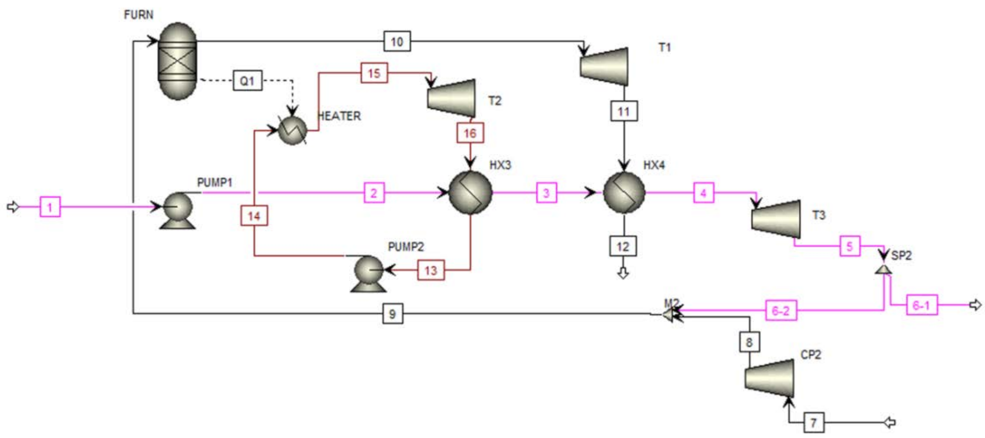
In this paper, the model of the combined power cycle of LNG cold energy recovery is constructed in Aspen Plus. How the turbine inlet and outlet pressure, the compressor outlet pressure, ammonia water flow rate and condensing temperature influence the cycle energy efficiency are made sensibility analysis so that the evidence of improving the cycle efficiency can be presented.

2 The Model of the Combined Power Cycle

The model of the process in constructed in Aspen Plus, as shown in Fig.1. In the simulation, the LNG flow rate is 1kmol/s. The LNG is composed of 0.82 CH_4, 0.112 C_2H_6, 0.04 C_3H_8, 0.009 nC_4H_{10}, 0.012 iC_4H_{10} and 0.007 N_2.Other parameters are shown in Table1. In simulation and calculation, it's crucial to calculate accurately the medium property, so the right property method is needed to choose. The NRTL model is used to simulation calculated the mutually soluble system, so the property method of ammonia water in Rankine cycle has been chosen correspondingly. And the property method of LNG is the state equation of SRK, while that of combustion gas is Peng-Rob state equation.

Table1 The setting of parameters in simulation

Parameter name	Value
Combustion efficiency in the furnace η_{furn}	0.99
The atmosphere temperature/$^\circ$C	25
The atmosphere pressure /MPa	0.1
LHV /（kJ/kg）	50056
LNG flow rate/(kmol/s)	1
Ammonia water flow rate /(kmol/s)	0.365
Ammonia water mole ratio	7:3



PUMP—pump, HX—heat exchanger ,CP—compressor, T—turbine, FURN—furnace, HEATER—heater Q1—heat flow

Fig.1 The model of the combined power cycle in Aspen Plus

3 Simulated Calculation

Thermal efficiency is used to measure the performance of thermal cycles. In the combined power cycle, thermal efficiency, namely the first law of thermodynamics, is defined as the ratio of the out work of total system and the input work of the heat source. The mathematical expression of the cycle thermal efficiency is shown as.

$$\eta_1 = \frac{W_{net}}{\eta_{furn} q_{m,6-2} LHV} \tag{1}$$

Here, $W_{net} = W_{out} - W_{in}$;

$W_{out} = W_{T1} + W_{T2} + W_{T3}$;

$W_{in} = W_{P1} + W_{P2} + W_{CP}$.

Where, η_1 is the thermal efficiency. The total network is represented by W_{net}. W_{out} and W_{in} are the output and input work of the system. W_{T1}、W_{T2} and W_{T3} represent the output work of the turbine T1、T2 and T3 respectively. W_{P1}、W_{P2} and W_{CP} represent the work of the PUMP1、PUMP2 and CP respectively. In addition, η_{furn} is the combustion efficiency in the furnace, and $q_{m,6-2}$ represents the NG mass flow rate at the point 6-2. LHV is short for low heat value of LNG.

4 Result and analysis

4.1 The influence of the inlet pressure of the turbine T3

As shown in Fig. 2, the thermal efficiency varies with the inlet pressure p_4 of the turbine T3 under different flow rates of ammonia water. With the same ammonia water flow rate, the efficiency increases with the pressure p_4, because the work of turbine T3 increases and yet the PUMP1 work reduces as the pressure p_4 increases. However, the increment of the turbine is more than the decrement of the pump, as shown in Fig.3, so the network of the total cycle increases as well, which leads to the improving of the thermal efficiency. When ammonia water flow rate increases under the same pressure, the changing tend of thermal efficiency goes down. Since ammonia water flow rate increasing, the additional work of PUMP2 is needed. What is more, given the same heat in the furnace, the temperature of ammonia water, that is, the stream temperature at the inlet of turbine T2 would be lower, so that the turbine T2 work would be reduced. Therefore, the decreasing of the network results in the thermal efficiency reducing.

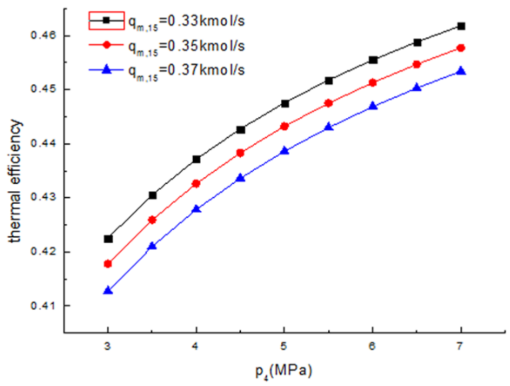


Fig.2 Variation of thermal efficiency

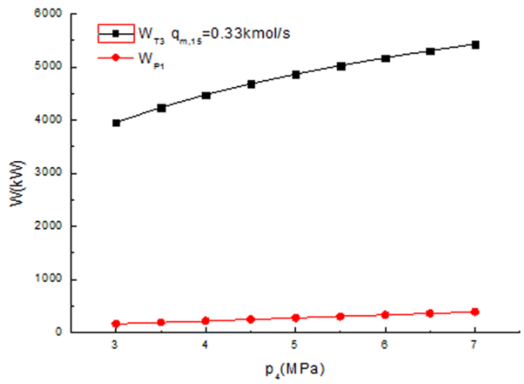


Fig.3 The work of the T2 and PUMP1

4.2 The influence of the outlet pressure of the turbine T3

The thermal efficiency decreases with the increasing of the outlet pressure p_5 of the turbine T3(in Fig.4). Because the reduction of the work of the T3 resulting from the increasing of the pressure p_5 is more than the increment of the T1. Why the increasing of the T1 work is that the pressure p_5 effects the pressure at inlet of the gas turbine T1.

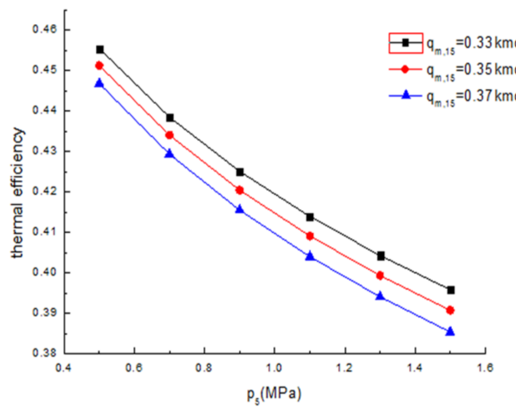


Fig. 4 Variation of thermal efficiency

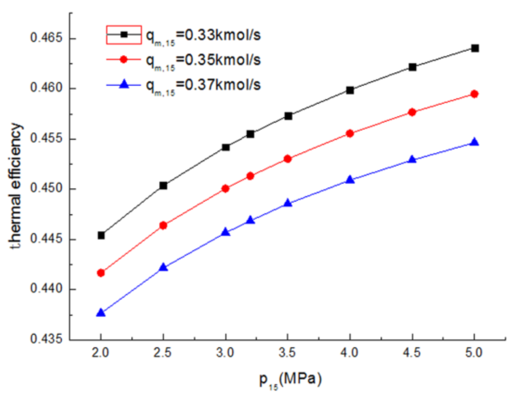


Fig.5 Variation of thermal efficiency

4.3 The influence of the inlet pressure of the turbine T2

The thermal efficiency increases with the inlet pressure p_{15} of the turbine T2, as shown in Fig.5. Increasing of the T2 inlet pressure, which is equal to the outlet pressure p_{14} of PUMP2 ignoring pressure drop, results in the additional work of the PUMP2 and T2. Meanwhile, the increment of the PUMP2 is less than that of the T2, so the increasing of the network makes the trend of the thermal efficiency rise.

4.4 The influence of the condensing temperature

The condensing temperature of ammonia water has an effect on the back pressure of the turbine which influence the work of turbine T2. With the condensing temperature going up, the vacuum, the turbine T2 back pressure is dropped resulting in the work of the turbine decreasing, and the total network is affected by the work of the turbine T2 further. Therefore, the thermal efficiency is reduced, as shown in Fig.6. In this literature [9], the reason of the cycle thermal efficiency increasing with the condensing temperature is that how the condensing temperature affects the vacuum of the turbine and the direct correspondence between condensing temperature and pressure are neglected. However, the literature [1]and [6] have the same result with this paper.

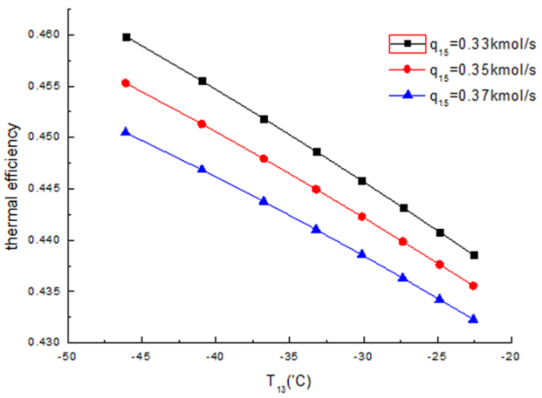


Fig. 6 Variation of thermal efficiency

4.5 The influence of the outlet pressure of the compressor CP

There is a direct relation between the exhaust pressure of the compressor CP and the pressure at the outlet of the gas turbine T1. With the compressor exhaust pressure increasing, the additional work of the compressor is needed, and the gas turbine work T1 also increases. Even though the increment of the gas turbine work is less than that of the compressor, the T2 work also increases (in Fig.8). So the network goes up and the thermal efficiency increases with the compressor outlet pressure (in Fig.7).

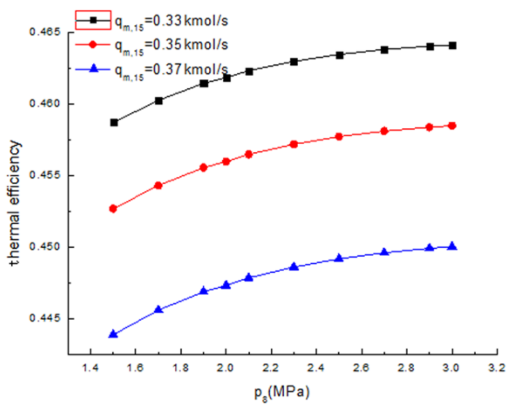


Fig.7 Variation of thermal efficiency

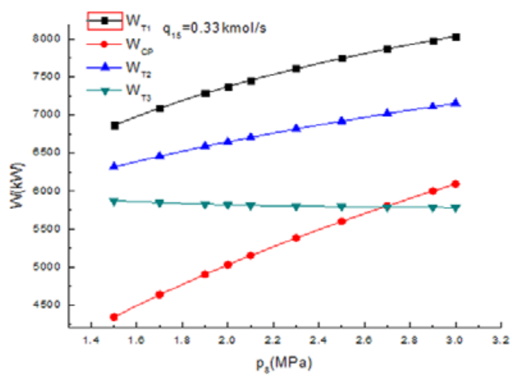


Fig. 8 The work of the turbine T1, T2, T3 and the compressor CP

5 Conclusion

In this paper, the effects of some key parameters including the compressor exhaust pressure in Brayton cycle, the inlet pressure of ammonia turbine, condensing temperature and the inlet and outlet pressure of LNG turbine to the thermal efficiency under different ammonia water flow rate have been made sensitivity analysis. The thermal efficiency increases as the compressor exhaust pressure and the inlet and outlet pressure of the turbines increase, and yet ammonia water flow and condensing temperature decrease.

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