Numerical Study of the Effect of the Helium-based Multi-component Gas Mixture on the Internal Purifier

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Abstract

The performance of the internal purifier has a direct impact on the liquefaction capacity of the helium liquefier. With increasing impurity level in helium, liquefaction capacity of the helium liquefier reduced significantly. In order to ensure the helium liquefier operates safely and stable, remove the impurities from the helium in the helium liquefier and improve the utilization of the helium, it is necessary for us to develop the technology of purification. In this paper, the impact of changes of multi-component helium mixture on the performance of the internal helium has been developed numerically. The final results show that as the impurities in the helium mixture increases, the performance of the internal purifier decreases first and then increases. It can help us design more efficient and compact internal purifier.

Conclusion

Through analysis, the results show that in the process of condensation, separation and purification of helium-nitrogen mixture, the UA value of FTWHE decreases first and then increases to a certain extent with the increase of nitrogen component. The minimum UA value appears at about 90% of helium gas volume component. In the simulation process of condensation separation and purification of helium-oxygen mixture, the effect of oxygen component on UA value of FTWHE is basically the same as that of helium-nitrogen mixture. UA value decreases first and then increases with the increase of oxygen component volume, but the minimum UA value appears at about 95% of helium component. According to the numerical results, the heat exchanger is designed according to the minimum UA value, which ensures the safety and reliability of the heat exchanger.

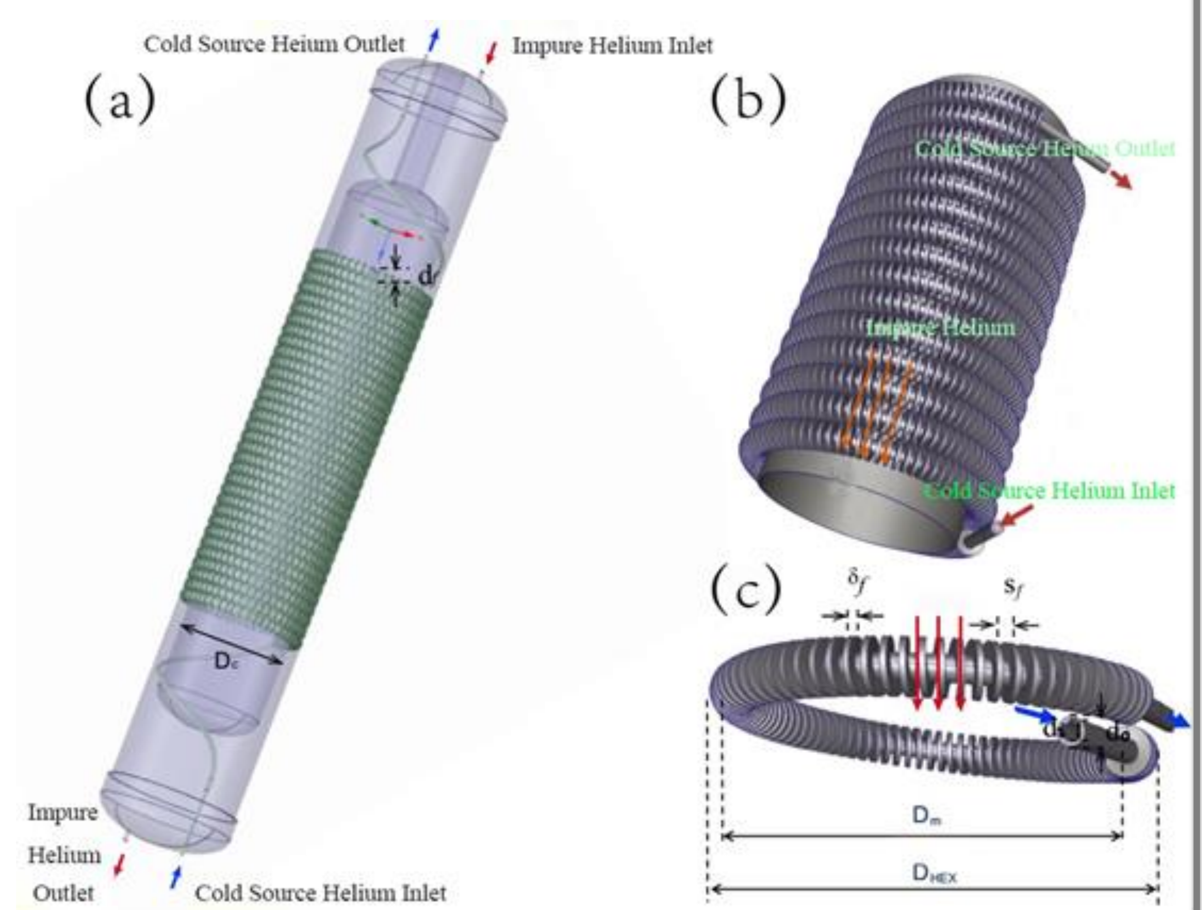
Introduction and Numerical Model

The Reason of Built FTWHE

The internal purifier plays an important part in the purification of impure helium. It is installed inside the coldbox and utilizes the cooling capacity of the coldbox to condensate, freeze and separate impurities. And it has the advantages of high integration, effective purification, maintenance friendly and high degree of automation.

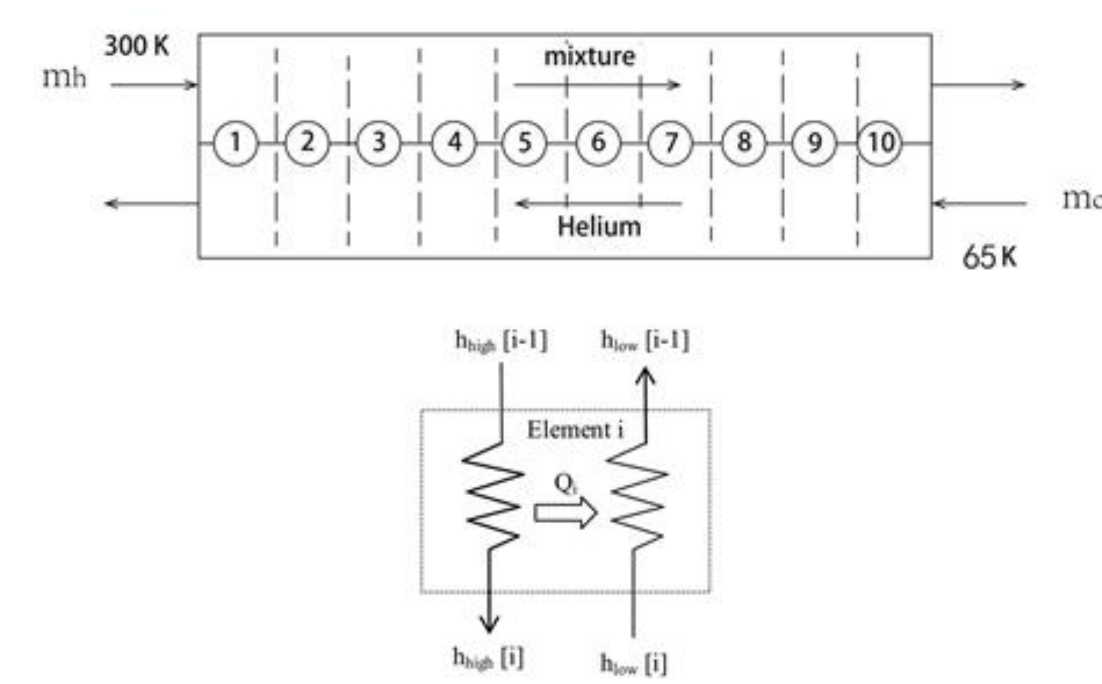
Present problem is that data on how to design, fabricate and test the performance of heat exchangers for the internal purifier lacks, especially lacking specially research which discusses from the numerical view.

In this paper, a simplified model of heat and mass transfer for the first stage heat exchanger of the internal purifier has been built. The impact of changes of multi-component helium mixture on the performance of the internal helium purifier has been developed numerically.



The first stage heat exchanger of the internal purifier: the Finned tube wound heat exchanger (FTWHE)

Establishment of the Numerical Model



A schematic view of a single element and heat transfer of FTWHE

In this investigation, the Finned tube wound heat exchanger (FTWHE) has been divided into elements, where each element consists of a single band of the helical finned-tube.

The model will be investigated based on the following assumptions.

(1) The axial heat conduction through mandrel is neglected, and the heat from the impure helium to the cooling source helium is transferred through finned-tube wall.

(2) The physical properties of helium and impure helium at every single element of FTWHE remain the same.

According to the Law of Conservation of Energy, a single element the equation is given by

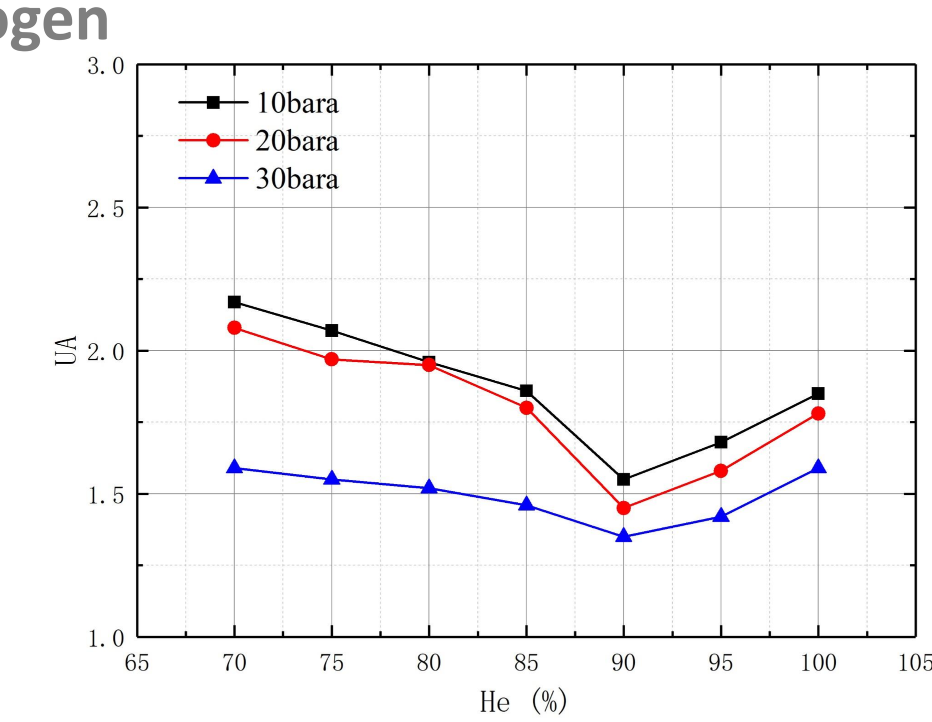
$$h_{high}[i-1]-h_{high}[i]=h_{low}[i-1]-h_{low}[i]=dQ_i$$

Results and Discussion

Binary Mixture of Helium and Nitrogen

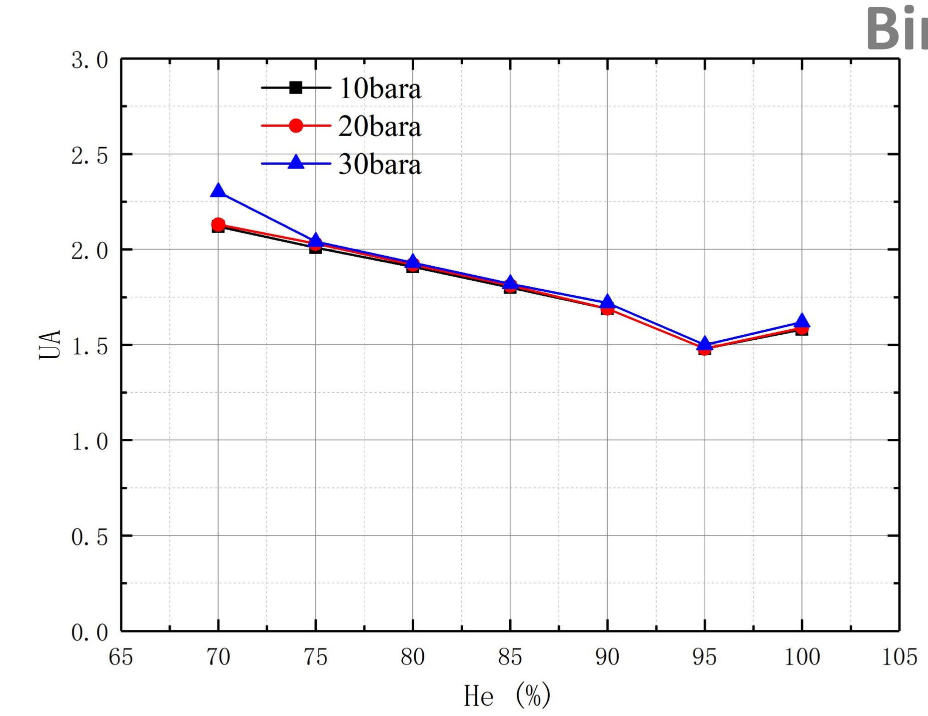
In a helium refrigeration system, the pressure of recovery and purification of impure helium is generally less than 30 bars. Therefore, in the process of numerical simulation, the impure helium pressure is simulated in the range of 10 bar to 30 bar. And the pressure of the cooling source helium is 7 bara. Among binary helium-based gas mixtures, the volume fraction of impurity gases is up to 30%. Based on the above conditions, the influence of impurity gas in impure helium on UA value of FTWHE under different partial pressures is investigated.

As the nitrogen component continues to increase, UA value gradually increases after reaching the minimum value. This is mainly because the contribution of nitrogen condensation heat exchanger to UA value is greater than that of heat transfer resistance produced by liquid film formed by nitrogen condensation, so UA value increases.



Under pressure of 10 bara, 20 bara and 30 bara, the UA values vary with the composition of helium-nitrogen mixture

Binary Mixture of Helium and Oxygen



Under pressure of 10 bara, 20 bara and 30 bara, the UA values vary with the composition of helium-oxygen mixture

It clearly indicates that UA value of the FTWHE first descended and then raised with the increase of oxygen content. This is basically consistent with the variation trend of helium-nitrogen mixture gas composition. The difference is that the minimum UA value of helium-oxygen mixture occurs at 95% of helium volume fraction, while the minimum UA value of helium-oxygen mixture occurs at around 90% of helium volume fraction. The reason for this is that the physical properties of nitrogen and oxygen are different.

The UA value of heat exchanger is also affected by different pressure. With the decrease of pressure, UA value tends to increase. The helium-nitrogen mixture is obvious in this aspect, but the helium-oxygen mixture is not so obvious. The main reason for this is that the boiling point of oxygen is lower than that of nitrogen, and most of oxygen becomes liquid at low temperature, while the amount of liquefaction of nitrogen is less than that of oxygen, so the influence of pressure on helium-oxygen mixture is less.

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