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A new type of helium purifier which uses a GM cryocooler as the cold source

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Abstract. This new type of helium purifier developed by CSIC Pride (Nanjing) Cryogenic Technology Co. Ltd. (hereafter called Pride) uses its own 10 K GM cryocooler KDE210SA-KDC6000V (1st stage ≥ 60 W @ 65 K, 2nd stage ≥ 20 W @ 35 K) as the cold source. This new type of helium purifier can increase the purity of helium gas from 95% to over 99.999%, and its purification capacity is up to 10 Nm³/h. Purification time is over 12 hours and regeneration time is less than 6 hours. The purification principle of this helium purifier is cryogenic condensation and freezing, Pride has an exclusive patent for this technology (Patent number is US9752824). Compared with the traditional cryogenic absorption helium purifier, its key advantage is that to operate the purifier only needs electric power and cooling water, with no need for liquid nitrogen. Such a purifier has been used in Chinese institutes, universities and gas factories, and can be integrated with a helium liquefier to form a whole system.

1. Introduction

The traditional helium purification methods include membrane separation, physical adsorption and low temperature distillation [1]. Our helium purifier breaks with the traditional methods, which use GM cryocoolers as a cold source to separate the impure gas by cryogenic condensation and freezing, to finally get 99.999% purity helium gas. Because the cold source is a GM cryocooler, the structure of our helium purifier can be very simple and the whole system can work reliably only by using electric power and cooling water. Such a helium purifier has been sold to famous institutes, universities and industrial customers in China and overseas. When the purity of the helium gas is higher than 95%, the purification capacity can be over 10 Nm³/h

2. System design

The impurity inside the low purity helium gas is normally air; the main components are nitrogen, oxygen, neon and so on [2]. The helium purifier developed by our company uses a 2-stage gas separation method to remove the impure gas, whose cold source is the KDE210SA-KDC6000V GM cryocooler, as shown in figure 1. The load map of this GM cryocooler is shown in figure 2. The KDE210SA-KDC6000V is a 2-stage GM cryocooler, whose 1st stage cooling power at 65 K is higher than 60 W, whose 2nd stage cooling power at 35 K is higher than 20 W, and whose power consumption is less than 7.5 kW.





Figure 1. KDE210SA-KDC6000V cryocooler.

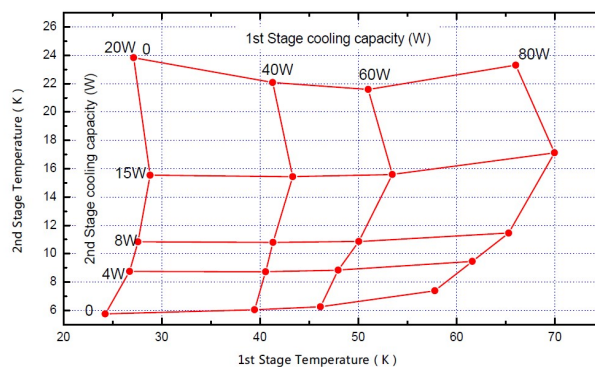


Figure 2. KDE210SA-KDC6000V load map.

Figure 3 is the principal flow chart of this helium purifier, which uses the GM cryocooler described above as its cold source. The whole system consists of a helium purifier shell, cold box, heat exchanger (inside the cold box), gas-liquid separator, GM cryocooler and so on.

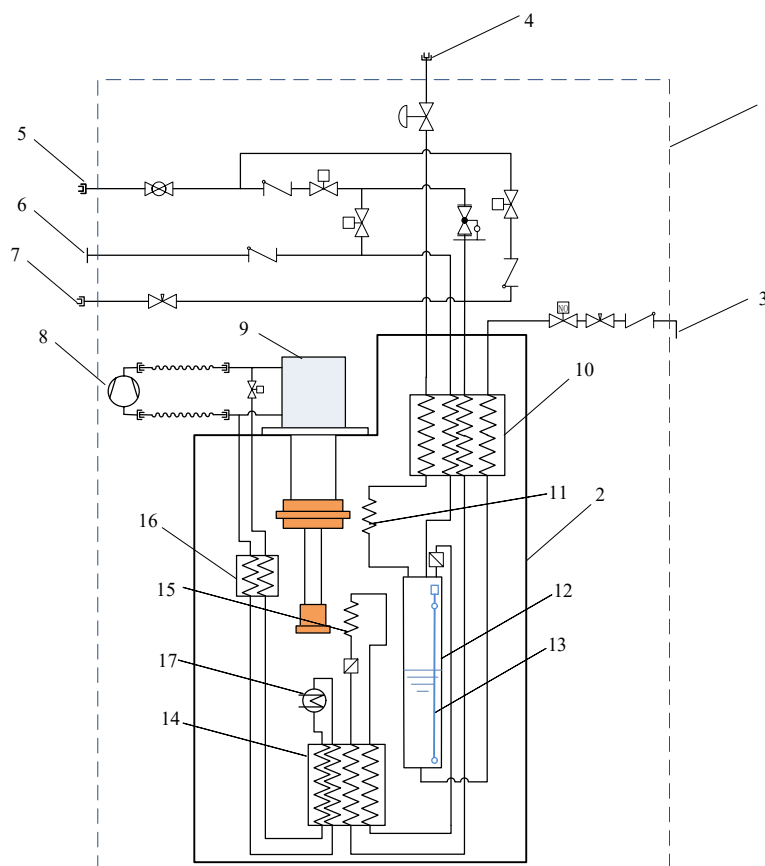


Figure 3. 1. Purifier shell 2. Cold box 3. N₂, O₂ gas exhaust port 4. Impure helium gas inlet port 5. High purity helium gas outlet port 6. Impure helium gas exhaust port 7. Sample analysis port 8. KDC6000V Helium compressor 9. KDE210SA Cold head 10. 1st stage regenerative heat exchanger 11. 1st stage cold head heat exchanger 12. Gas-liquid separator 13. Liquid level sensor 14. 2nd stage regenerative heat exchanger 15. 2nd stage cold head heat exchanger 16. Regeneration heat exchanger 17. Regeneration heater

The working process of the new type helium purifier includes a purification process and a regeneration process. During the purification process, the high pressure (2–5 MPa) raw helium gas will flow into the 1st stage regenerative heat exchanger and be precooled by the back-flow helium gas. The working temperature of the 1st stage of KDE210SA cold head will be set and controlled to be around 65 K (the triple point temperature of nitrogen gas is 63.15 K). Part of the nitrogen gas and oxygen gas will be condensed to form liquid and stored in the gas-liquid separator. The liquid level sensor inside the gas-liquid separator will monitor the liquid level in real time and control the degree of opening of the N₂/O₂ gas exhaust valve, enabling precise control of the liquid level in the gas-liquid separator. The cooling power of the liquid nitrogen and oxygen from the bottom of the gas-liquid separator will be recovered by the 1st stage regenerative heat exchanger. After the preliminary purification, the impure helium gas will flow into the 2nd stage regenerative heat exchanger and be cooled to be below 40 K; here the remaining nitrogen and oxygen gas will be frozen inside the inner pipe of the 2nd stage regenerative heat exchanger at below 40 K, thus producing high purity helium gas (> 99.999%). After the high purity helium gas is cooled to below 40 K using the cooling power of the 2nd stage of the cold head, it will flow through the warm tunnel of 1st and 2nd stage regenerative heat exchangers, cooling the incoming flow of impure helium gas. After recovering its cooling power, the high purity helium gas will be exhausted outside the helium purifier.

Because there is nitrogen and oxygen frozen inside the 2nd stage regenerative heat exchanger constantly, the flow resistance of the high temperature side of the 2nd stage regenerative heat exchanger will increase. When the pressure difference reaches a set value, the helium purifier will switch to the regeneration process automatically.



Figure 4. Actual photo of KDHPS-CC helium purifier.

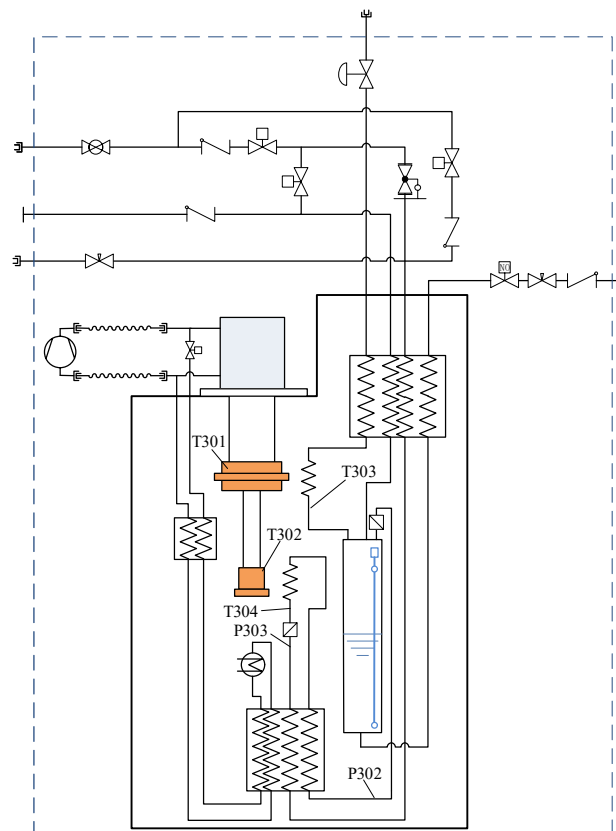


Figure 5. Temperature and pressure monitoring points.

During the regeneration process, the cold head will shut down and the regeneration heater will start to work. The by-pass recycling helium gas will transfer the heat from the regeneration heater to the 2nd stage regenerative heat exchanger; the solid nitrogen and oxygen will convert to the gaseous state and be discharged outside the 2nd stage regenerative heat exchanger.

Figure 3 is a photo of the helium purifier which uses the GM cryocooler as its cold source; its model type is KDHP5-CC and the dimensions are 1230 mm × 850 mm × 2070 mm (L×W×H). The cold box, KDC6000V helium compressor, control unit and other accessories are integrated into the helium purifier shell. The whole system is moveable and can work immediately when the helium gas inlet, helium gas outlet, power supply and cooling water supply are all correctly connected.

3. Performance test

The temperature and pressure monitoring points are shown in figure 5. PLC control and a touch screen are used in this helium purifier. The valve opening state, the system pressure, temperature and other information is shown on the screen.

There is a temperature sensor, T303, installed on the inlet port of gas-liquid separator and a temperature sensor, T304, installed on the inlet port of the heating tunnel of the 2nd stage regenerative heat exchanger. There are pressure sensors, P302 and P303, installed separately on the inlet port and outlet port of the 2nd stage regenerative heat exchanger to monitor the pressure difference in real time.

During the working cycle of the helium purifier, control of the helium gas temperature entering the gas-liquid separator at about 65 K (the triple point temperature of nitrogen gas is 63.15 K) ensures most of the impurities will be separated into the gas-liquid separator. The purity of the helium gas exiting the helium purifier is judged by the temperature of the inlet port of the heating tunnel of the 2nd stage regenerative heat exchanger. The start-up of the regeneration process is determined by the pressure difference between the inlet port and outlet port of the 2nd stage regenerative heat exchanger.

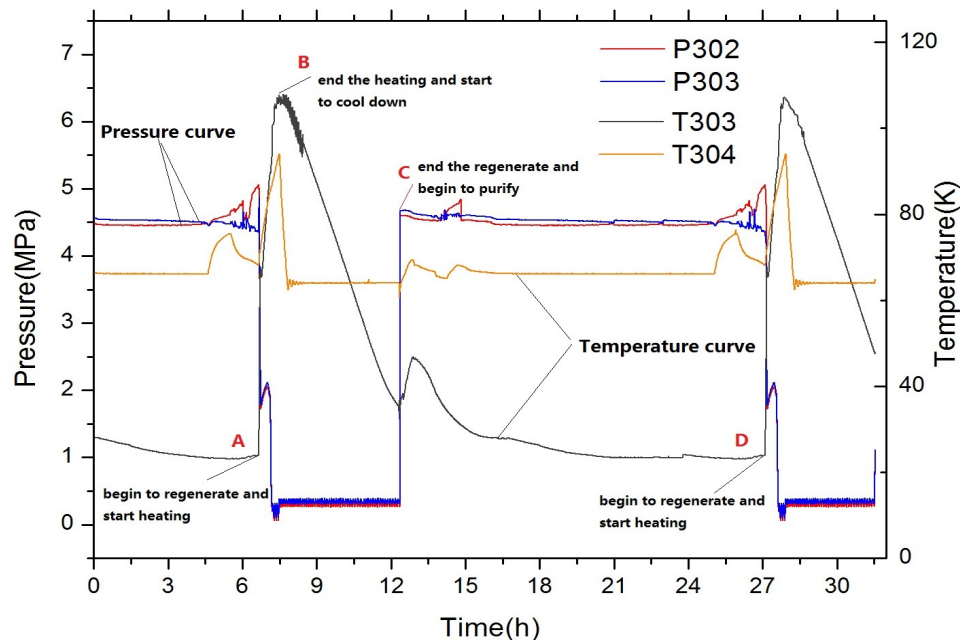


Figure 6. Temperature and pressure curve during the working time of helium purifier.

The system's working temperature and pressure curves during the whole operating process is shown in figure 6. At point A, the purifier starts the regeneration process during which time the cold head does not operate. The by-pass recycling helium gas from the helium compressor work together with the regeneration heater to warm up the 2nd stage regenerative heat exchanger quickly. At point B, the regeneration process is finished and the purifier starts the cooling process (no inlet gas). At point C,

the cooling process is finished and the purification process starts. At this stage, the inlet helium gas flow rate is 10 Nm³/h and the working pressure is 4.6 MPa. At point D, the purification process is finished and the purifier changes to the regeneration process automatically. So from point A to point C, the purifier is undergoing regeneration and the whole process takes less than 6 hours. Meanwhile, from point C to point D, the purifier is in the purification process and the working time is over 12 hours. Therefore the ratio of purification time to regeneration time is greater than 2:1.

During the purification process, when the temperature of T304 is below 40 K, the content of the impure gas is less than 10 ppm according to test results. Under these conditions, the helium gas is taken as high purity (> 99.999%) and can be injected into high purity gas cylinders or a helium liquefier. When the temperature of T304 is over 40 K, the helium gas purity is not guaranteed and it should be discharged into an air bag or impure gas cylinders. There is no need for the installation of a purity monitor as simply by monitoring the temperature of T304 it is possible to make a judgement whether the purity of the helium gas is acceptable; the lower the temperature, the higher the purity. This kind helium purifier has been integrated into a helium liquefaction system and there have been no blockages in the liquefier for almost 3 years.

4. Conclusion

The new type helium purifier described in this paper, which uses a GM cryocooler as its cold source, has the advantages of compactness and easy operation. The by-pass recycling helium gas from the helium compressor is used in the regeneration process to reduce the regeneration time. Meanwhile, it is only necessary to monitor the temperature in order to make a judgment on the quality of the helium gas. With this purifier is integrated with our company's helium liquefier, customers using liquid helium will save money.

5. Reference

- [1] Jinhui Y and Hongyu B 2006 Helium purification in large scale cryogenic system *Cryogenics* **4** pp 28–32.
- [2] Bondarenko V L and Simonenko Y M 2013 *Cryogenic technologies of rare gases extraction* (The Academic Council of the Odessa National Academy of Food Technologies)