The design and study of a reciprocating helium compressor

Lei G.[1,2], Gong L-H.[1], Lu W-H.[1], Zhang L.[1]

[1]Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100080, China
[2]Graduate School of Chinese Academy of Sciences, Beijing 100039, China

This paper discusses the possibility and the performance of a helium compressor modified from a commercial air conditioning, reciprocating compressor. Modifications to the compressor include an oil injection system and new type lubricant. The exhaust helium temperature will be much higher than that allowed if we just operate this compressor without any modifications. Hence a new cooling method has been developed to intensify the heat exchange of the helium gas in the cylinder with the lubricant oil so an acceptable lower discharge temperature can be obtained. A temperature reduction of more than 70℃ was achieved in the experiments.

INTRODUCTION

This paper focuses on the modification of a commercial air conditioning compressor with the input power of 7.5 kW. The discharge temperature of the compressed helium gas will exceed 180℃ if we do not improve its original cooling system . The new type lubricant oil is processed to remove the water content before we operate the machine. A by-pass valve is set in the oil injection circuit to control the atomizing pressure and mass flow rate of the oil through the atomizers so we can get an optimum value of the injection pressure in various operating conditions.

A new cooling system was developed to solve this problem. An oil pump was adopted to make an oil injection circuit. The lubricant oil injected into the low-pressure chamber of the compressor is atomized when forced through three swirl-type pressure atomizers. Some of the oil particles will be sucked into the cylinders with the helium flow and compressed together with the helium gas, which is called inner cooling. And a high performance filter was also used to remove the contaminant oil from helium gas so pure helium gas should be obtained. The results of our experiments show that this method is feasible.

SYSTEM DESCRIPTION

This experiment system is composed of the compressor module, an oil pump, two plate-type heat exchanger, a multi-stage oil separator (2 or 3 stages), an adsorber and a reservoir. Figure 1 illustrates the setup configuration of the modified compressor system.

The oil injection circuit

A gear pump with the volume flow rate of 0.1 L/s was chosen to circulate the lubricant oil. The power consumption of the motor to drive this pump is 800 W.

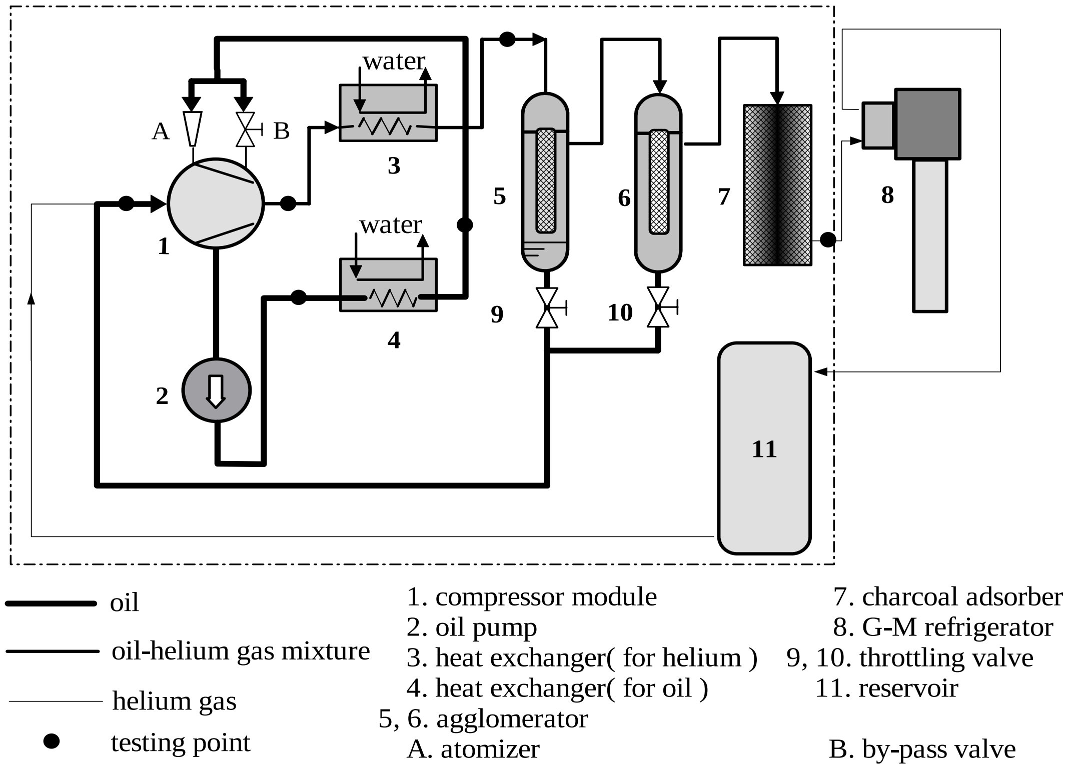

Figure 1 Modified helium compressor system (inside the dashed)

The atomizers

The atomizers play an important role in the inner-cooling circuit. The lubricant oil forced through the atomizers should be fully atomized so that part of the tiny oil particles can be sucked into the cylinders to remove the compression heat of helium gas. And the pressure drop of the atomizers should not be too high thereby relative low power consumption and lower noise level of the oil pump can be obtained. We select the centrifugal pressure type atomizer that has been wildly used in many industrial facilities as a burner. The cross section of the atomizer is shown in Figure 2.

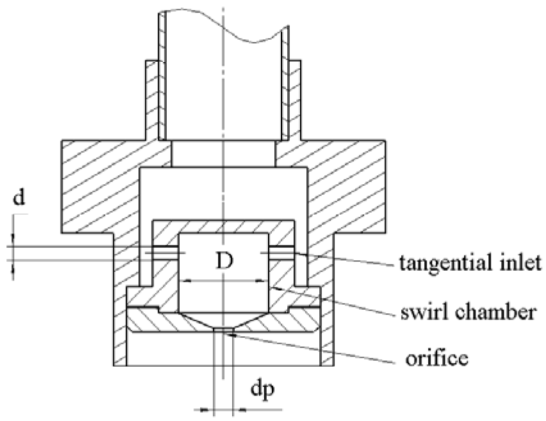

Figure 2 Cross section of the centrifugal pressure type atomizer

First the lubricant oil is forced through three tangential inlets symmetrically arranged surround the top end of the swirl chamber and then injected through the outlet by the effect of the centrifugal force and the differential pressure into the low-pressure chamber of the compressor.

The degree of atomization is mainly affected by the tangential and axial velocity components and the ratio of the orifice length to its diameter. A series of nozzles with different size (the diameter of the spin chamber, the radius of the inlet and the length and the radius of the orifice) were manufactured so we can find an optimum combination among these sizes by testing them respectively.

The spraying angle is theoretically given by:

$$\tan(\theta/2) = \frac{(V_t)_0}{(V_v)_0} \qquad (1)$$

with θ : plane cone angel including all the spray, usually measured close to the orifice where it is well defined, $(V_t)_0$: tangential velocity component at orifice wall, $(V_v)_0$: average axial velocity component computed as though the orifice were running full.

Equation (1) is an oversimplification of complex velocity relationships and does not hold for small orifices or a large L/d_p ratio.

The spaying angle from the swirl-type pressure atomizers can be used as a criterion or factor of comparison for fineness of atomization for different atomizers operating under identical conditions of pressure and flow rate. Thus, the atomizer exhibiting the largest cone angle will produce the smallest drop size [1]. This makes it quite easy to identify which nozzle has the better performance of atomization by measuring the angel of the corn.

The oil-separator and adsorber

During the compression process the oil particles entrained the helium gas. Depending on the study of the two-phase flow through porous media [2,3], a three-stage oil separator was designed to remove thoroughly the oil contaminants. The helium-oil mixture first enters a cyclone through a tangential inlet, and the testing results show that more than 98% of the oil was separated from the helium gas by the centrifugal force in this stage. Then the helium gas flowed through a foam-catchers made by stainless steel fiber with fiber diameters of 5 to 10 micrometer, where the relative large size oil particles were trapped. Finally the helium gas entered the agglomerator filled with superfine glass-fiber. The tiny oil particles will accumulate on the fiber surfaces and drip to the bottom of the agglomerator. All the trapped oil was returned to the compressor module. The remaining vaporous contaminants will be adsorbed onto the activated charcoal, allowing only pure helium gas to travel onto the cold head.

TEST RESULTS

Figure 3 shows the variation of the spray angle when the orifice length is changed. All the experiments done are with the same testing pressure of 9.8 bar. The spray angle decreased when the length of the orifice was changed from 0.3mm to 0.2mm. Later investigation indicates that this abnormality results from the irregularity of the orifice caused by the insufficient machining precision of the drilling machine. So a 0.3 mm was chosen as the diameter of the orifice.

The temperature of the exhausting helium gas from the compressor module was measured by a

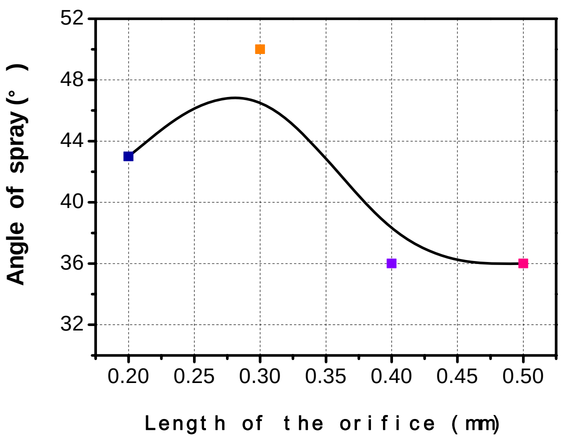

Figure 3 Comparison of spray angle with different orifice length (the other parameters of the atomizer are the same).

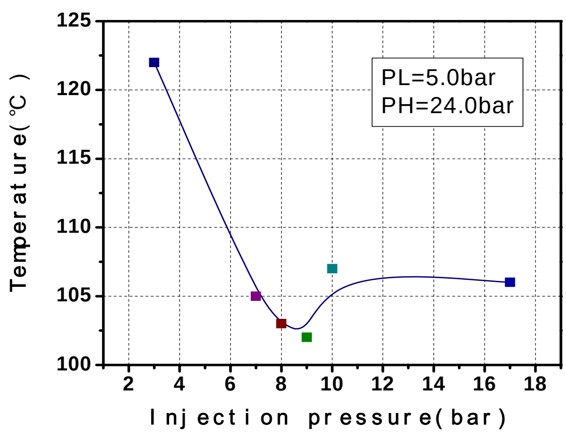

Figure 4 Measured discharge helium temperatures as a function of injection pressure of lubricant oil.

copper-constantan thermocouple located on the helium line. The atomizing pressure was controlled through changing the opening of the bypass valve set parallel with the atomizers in the oil injection circuit. So a pressure range from the minimum pressure (a little more than the pressure in the low pressure chamber of the compressor) to the maximum pressure of 17 bar. The testing results are shown in figure 4. The lowest exhausting helium temperature of 102 degrees centigrade was obtained when the atomizing pressure was set at 9bar. And this optimum atomizing pressure varies a little as the compressor was operated in a series of different conditions. Table 1 shows the specifications and typical operating parameters of the prototype compressor compared with the compressor package of the AL330 cryorefrigerator manufactured by Cryomech Inc. [4].

Table 1 Specifications and typical operating parameters

Unit	Prototype	Compressor package of AL330
Compressor Type	Reciprocating (hermetic)	Scroll (hermetic)
Oil Type	PAG (UCON LB300X)	PAG (UCON LB300X)
Power Supply	380 @ 50 Hz	380 @ 50 Hz
Operating Pressure (bar)	Discharge: 10.5-26.0 Suction: 2.0-5.2	Discharge: 6.5-24.0 Suction: 2.0-9.0
Helium Flow (Nm^3/hr)	102	88.3
Oil Injection Flow (L/s)	0.1	0.1
Nominal Motor Output (kW)	7.2	5.17
Max. Discharge Line Temp. (℃)	102	85
Temp. of Helium into Heat Exchanger (℃)	86-102	66-85
Temp. of Helium at Heat Exchanger outlet (℃)	22	29.4

During an extended service of more than 1,000 hours, the modified compressor ran stably without any problem. With the ongoing improvement of the agglomerator, a lifetime of more than 8,000 hours should be obtained without a replacement of the adsorber.

REFERENCES

1. Marshall, Jr. W. R., Atomization and Spray Drying, The Science Press, USA (1954)
2. Scheidegger, A. E., The Physics of Flow Through Porous Media, Toronto ; Buffalo [N.Y.] : University of Toronto Press, (1974)
3. T. Frising, V. Gujisaite, D. Thomas, S. Callé, D. Bémer, P. Contal & D. Leclerc, Spraying Angle and Spray Polydispersity in Modeling of the Aerodynamic Characteristics of FGD Towers. Filtration and Separation (2004) 41(2) 37-40
4. Cryomech Inc. The Manual of AL330 Cryorefrigerator.