Experimental and Computational Studies of Heat Transfer for Wall-type and Fin-type Heat Exchanger

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Abstract

Wall-type heat exchanger (WTHX) and Fin-type heat exchanger (FTHX) are attached to the first and second stage cold head of two G-M crycoolers respectively in the simulating experimental platform of the internal purifier (SEPEIP). WTHX and FTHX play a significant role in SEPEIP, WTHX is designed to remove heat from helium and freeze-out extremely few impurities, FTHX is for further cooling the helium. In this study, numerical simulation and experimental results for WTHX and FTHX are carried out. According to the comparison, Numerical results are well consistent with the experimental results. It is presented the better performance of the WTHX and FTHX.

Introduction

During past decades, several researchers have put much attention on the development of purification method and progress. In 1974, Collins firstly studied the purifying method, namely, using condensation, frozen and separation technique to acquire pure helium[3]. In 1983, technicians of Linde Kryotechnic developed the first internal purifier which was installed in the TCF type helium liquefier, that focusing on the purification circuit[4]. In 2015, Lozano et. al. compared the cleaning efficiency, the energy consumption, the initial investment and the cost of maintenance of two different methods applied for the purification of recovered helium with a low level of impurities[5].

However, none of these studies has been with respect to the performance of apparatuses in the internal purifier.

Main Objectives

In order to investigate the performance of the internal helium purifier, it is essential to establish an experimental platform to examine the purification features for each apparatus in the internal helium purifier. We aim to build an experimental platform that can successfully provide sufficient cold power to the experimental internal purifier. In this paper, attention is concentrated on the specific presentation of the WTHXs and FTHXs that are mounted separately on the two stages of G-M cryocoolers in the experimental platform. The performance characteristics of the WTHXs and FTHXs are studied theoretically and experimentally. This paper seeks to testify the rationality of the WTHXs and FTHXs through comparing simulation results and experimental values.

Design and Description

Two G-M cryocoolers are applied in the pilot plant to cool the cooling source helium down to a proper temperature at which the mixture helium could be cooled down to below the boiling point. Thus impurities will be condensed or solidified on the cold surfaces, and then by analyzing the component of the mixture gas, the purification efficiency of the internal purifier is obtained. On the basis of that reason, WTHXs and FTHXs play a significant role in the pilot plant. The specific description and detailed dimensions are given in the Figure 1.

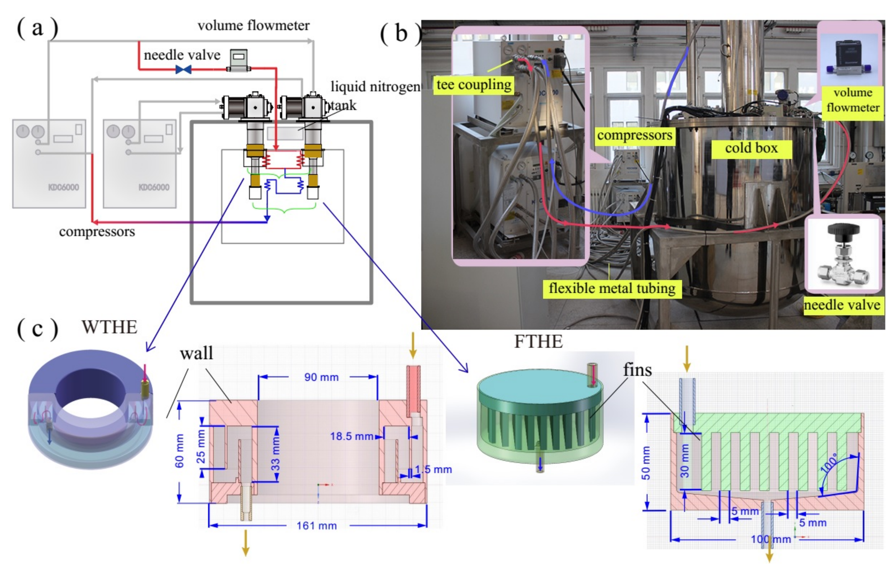

Figure 1: A cooling source process for the experimental platform. (a) Schematic of the flow process. (b) Photograph of the coldbox. (c) The internal structures and dimensions of WTHX and FTHX.

A 3 g/s compressed helium gas is split into two streams by a tee coupling, which is installed at the outlet of a compressor of GM cryocooler. One of that is 2.66 g/s going directly into the cold head and finally returning to the compressor. The other of that is 0.34 g/s going through a volume flowmeter and a needle valve and entering the coldbox. Then it is cooled down to 79 K with the precooling of boil-off liquid nitrogen. After that, it is taken into the heat exchangers mounted on the cold heads, where which is further cooled down to 34 K. At last, that helium gas is warmed to ambient temperature and returned to the compressor.

Simulation and Experimental Results

In this investigation, the governing equations numerically are solved by commercial computer program code Ansys Fluent. The simulations achieved in steady state regime, using viscous flow and k- model, which is appropriate for evaluation of helium flow and heat transfer inside the heat exchangers. We chose helium in the fluent database as the cell zone materials, which is very close to the practice. However, that physical properties do not vary with the temperature, attributing to the deviation from the experimental results.

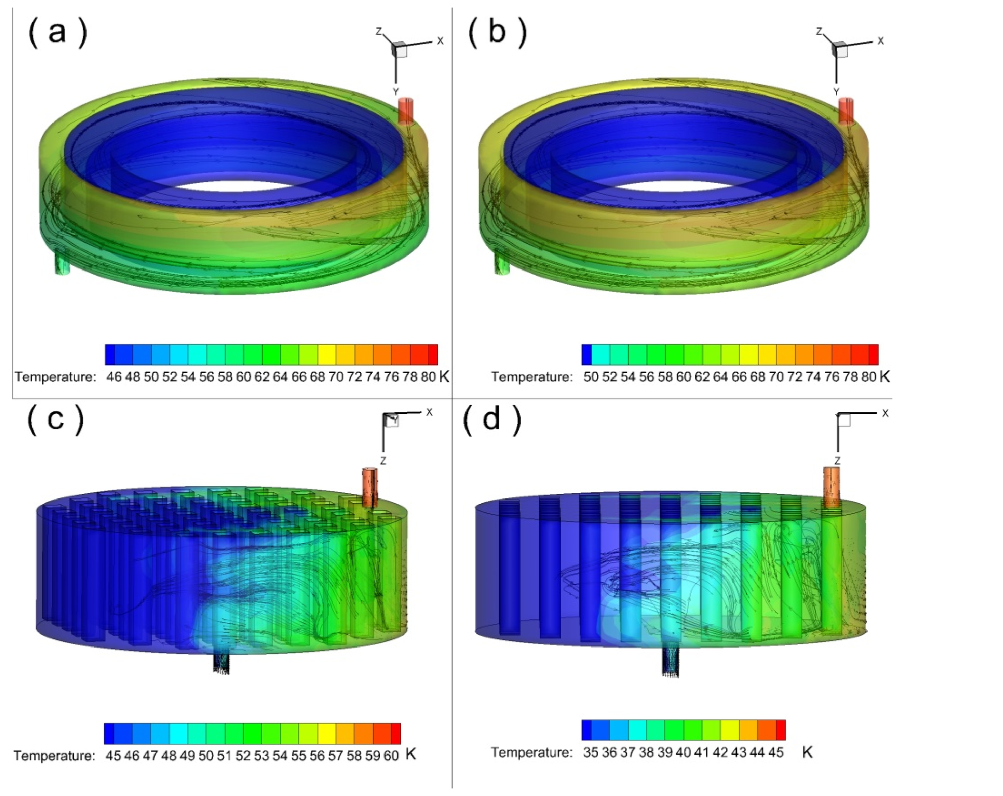

Figure 2: Temperature contours of two type heat exchangers. (a) Temperature contours of the left WTHX in Figure 1(a). (b) Temperature contours of the right WTHX in Figure 1 (a). (c) Temperature contours of the right FTHX in Figure 1(a). (d) Temperature contours of the left FTHX in Figure 1(a).

The simulation results are presented separately in the Figure 2. The quantitative data are revealed by contours of temperature. According to the simulation results, the temperatures of T1, T2, T3, T4, and T5 are 80 K, 60 K, 58 K, 45 K, and 35 K, respectively. After that, we interpret the results of experiments as in the following.

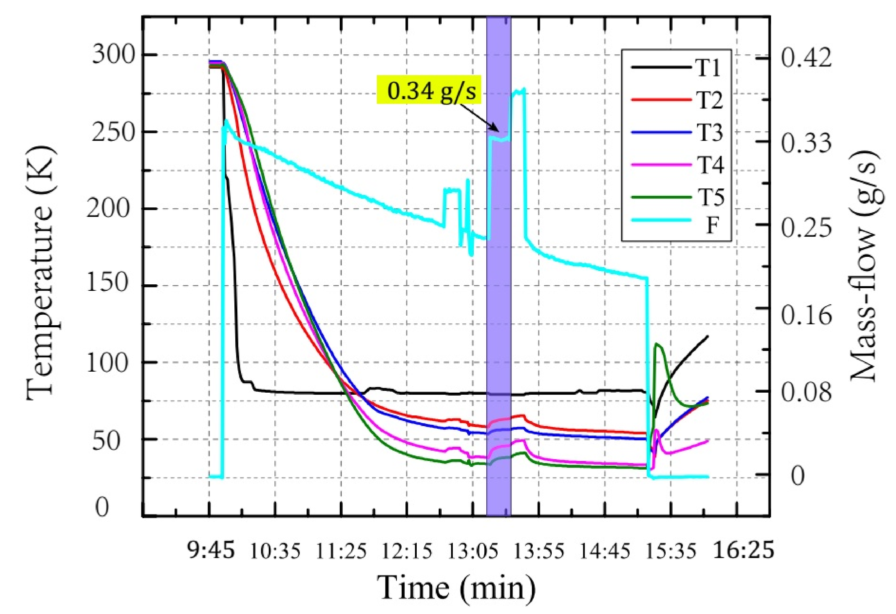

Figure 3: Temperature and mass flow of helium with time during the experiment. The F denotes the mass flow of the helium.

Experiments are performed to the helium refrigeration system when the purifier has not been applied. The separated helium flow is accurately controlled and measured by the volume flowmeter (shown in Figure 1), that flow rate is approximately 0.34 g/s. Moreover, it can also be adjusted by the needle valve in the circuit. Rhodium-iron resistance thermometers are used to measure the temperature at T1, T2, T3, T4, and T5. Then the test results with respect to time are presented in Figure 3. The experimental results are summarized as follows. The experimental process is divided into three periods: cooling period, helium flow adjustment period and rewarming period. In the cooling time, the temperature values vary linearly with the helium flow. In contrast, the helium temperatures are relatively steady in the adjustment period. It is shown that when the helium mass flow is 0.34 g/s, T1, T2, T3, T4, and T5 are 80 K, 63 K, 56 K, 45 K, and 38 K, respectively.

Discussion and Conclusions

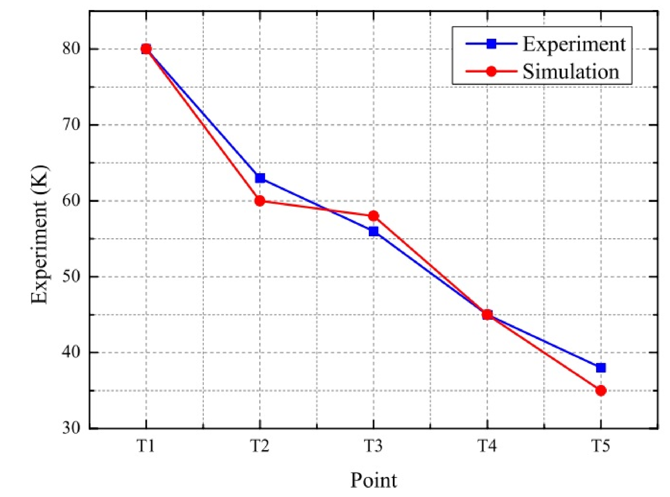

Figure 4: Results of experiment and simulation

According to the results, there is little discrepancy between experiment and simulation. That is probably a consequence of the influence of the radiation heat from surroundings. However, the deviation between those two results is acceptable. Therefore, we confirm that the simulation model and results are suitable for us to investigate the performance characteristics of the WTHXs and FTHXs. It provides some guidance information for improvement of the WTHXs and FTHXs. We have found that the helium temperature in the center of the WTHX is much lower than outer (shown in Figure 2). It seems that insufficient fluidity in the center accounts for this. Also, it is shown that heat exchange at the left of the FTHX is not excellent as at the right. The results may be due to the outlet at the center of the FTHX. Therefore, we believe if the outlet at the left of the FTHX effect of heat transfer would be better.

A helium refrigeration system for experimental investigation of internal purifier has been built and tested in this paper. It is also carried out to the simulation of WTHXs and FTHXs. Results show that simulation and experiment have a good consistency. They are capable of providing sufficient cold power to make the contaminants condense on the surface of the purifier. Notwithstanding WTHXs and FTHXs limitation, it is concluded that they are suitable to be applied in the refrigeration system and are capable of guaranteeing purifying experiment.