A SMALL AND LIGHT WEIGHT HEAT EXCHANGER FOR ON-BOARD HELIUM REFRIGERATOR

T. Koizumi, M. Takahashi, T. Uchida,
Y. Kanazawa, and M. Suzuki

Hiratsuka Research Laboratory,
Sumitomo Heavy Industries, Ltd., Japan

ABSTRACT

A small and light weight heat exchanger used for small helium refrigerator has been developed by Sumitomo Heavy Industries, Ltd.. This heat exchanger is a laminated metal heat exchanger which consists of perforated aluminum metal plates and glassfiber reinforced plastic separators. The size is from 100 mm to 28 mm in diameter and about 300 mm in length. The weight is from 2.5 kg to 0.6 kg. Also it can be used between room temperature and liquid helium temperature. The thermal efficiency obtained has been more than 96%. The heat exchanger has been practically used for on-board helium refrigerator in Japanese National Railways' superconducting magnetic levitated trains.

INTRODUCTION

Counterflow heat exchanger of high thermal efficiency is required for refrigeration and liquefaction systems. In recent years, many type heat exchangers, for example, Hampson, Collins and Plate-fin type have been developed. But these heat exchangers do not fit in with small refrigerators because the heat transfer area per unit volume of these heat exchanger is not large enough.

The small refrigerator, for example, on-board refrigerator in superconducting magnetic levitated trains, requires very small and high thermal efficient heat exchanger. Such heat exchanger must possess the following characteristics [1],[2].

1. Large heat transfer surface area per unit volume and per unit weight.

2. Very small longitudinal heat conduction through the walls in the exchanger.

3. Uniform distribution of flow throughout any cross section of exchanger.

4. High resistance to shock and vibration.

We have developed the small and light weight heat exchanger which fulfilled above requirements and applied it to on-board helium refrigerator in Japanese National Railways' superconducting magnetic levitated trains.

This paper describes the development of the laminated metal heat exchanger and its application for small refrigerator use.

CONSTRUCTION

The construction of laminated metal heat exchanger is illustrated in Fig. 1. This heat exchanger consists of a large number of parallel perforated aluminum metal plates, plastic separators and epoxy adhesives. The perforated metal plates and separators are alternately stacked and bonded with adhesives to build up the multilayer-body. Headers made of aluminum are bonded to both faces of the multilayer-body. Then, headers and multilayer-body are inserted into a thin walled stainless steel vessel with pipe fittings. One end of the fitting is welded to the stainless steel vessel and the other end is bonded to the header. Therefore, there is no gas leakage to the vaccum space, when the heat exchanger is installed in a vaccum space.

In this exchanger, gas flow passages are divided into eight sections and gas flows longitudinally in counterflow pattern. Heat transfers laterally from hot gas to cold gas through the perforated plates. The perforated heat transfer plate is made of aluminum which has high thermal conductivity and is 0.3 mm in thickness, with 0.5 mm diameter holes.

A thickness-to-diameter ratio is 0.6 in this perforated plate. It is represented that the desirable ratio is in the range 0.5 to 1.0 because thermal and hydrodynamic boundary layers are broken up before they have a chance to become fully developed, which results in high heat transfer surface coefficients [1].

The separator is made of glassfiber reinforced plastic which has low thermal conductivity and its thickness is 0.4 mm. Therefore, the longitudinal heat conduction through the walls in the heat exchanger is very samll.

Figure 2 is a photograph of this heat exchanger. This is applied to first stage heat exchanger for on-board refrigerator. The size is 80 mm in diameter and 250 mm in length and the weight is about 2.2 kg. The heat transfer area per unit volume in this heat exchanger is about 1000 m^2/m^3.

PERFORMANCE

TEST APPARATUS

The heat transfer and friction loss performance test apparatus is shown in Fig. 3. The test has been performed by using helium gas between room temperature and the liquid nitrogen temperature. The pressure of the high pressure line and low pressure line are 1.57 MPa and 0.1 MPa respectively.

High pressure helium gas flows through test heat exchanger and is throttled to low pressure by throttle valve and flows back to helium compressor through the heat exchanger. The temperature of gas flow is measured by copper-constantan thermocouple. The pressure drop is measured by differential pressure gage.

EXPERIMENTAL DATA

The heat exchanger shown in Fig. 2 has been tested. The hole diameter of perforated plate is 0.5 mm and open area ratio of the high pressure passage is 15% and low pressure is 30%. The gap between perforated plates is about 0.6 mm. The effectiveness and pressure drop versus the mass flow rate of helium are plotted in Fig. 4. It shows that when helium gas flow rate is 1 g/sec, 96.5% effectiveness is obtained and pressure drop is 0.008 MPa.

Another type laminated metal heat exchanger which we have fabricated is shown Fig. 5. The size of this heat exchanger is 28 mm in diameter and 300 mm in length. Headers and multilayer-body are inserted into the stainless steel vessel and their weight is about 0.6 kg. Obviously, it is much small and light in weight compared with the heat exchanger shown in Fig. 2.

RELIABILITY

ADHESIVE

The construction of laminated metal heat exchanger which we have described above is very simple. But for heat exchanger it is important to possess the effective adhesive strength, gas tight and good durability, because this exchanger is constructed with adhesive bonding.

So, we have selected many kinds of adhesives and tested their adhesive strength and gas leakage at low temperature to choose the best adhesive among them. The test results of epoxy adhesive which we applied to fabricate the heat exchanger is explained in the following.

ADHESIVE STRENGTH

We measured the strength of two different test specimens, one is aluminum-aluminum adhesive bonded joint, the other is aluminum-GFRP-aluminum adhesive bonded joint.

The shearing strength versus temperature is shown in Fig. 6. The results indicate that the shearing strength increases as the temperature decreases. The shearing strength of Al-GFRP-Al at liquid nitrogen temperature is about 15 MPa and the specimens failed in the adhesive. Also shearing strength denoted by triangles shows the test results after 7 thermal cycles between room temperature and liquid nitrogen temperature.

Fig. 7 presents the tensile strength versus temperature. The tensile strength of Al-GFRP-Al specimens at liquid nitrogen temperature is about 50 MPa. Some specimens denoted by squares were cycled 235 times between room temperature and liquid nitrogen temperature after one year has passed since they were bonded. Their tensile strength were nearly equal to the other specimens. Also the failed surface displayed a cohesive failure in adhesive.

EFFECT OF THERMAL COOLING

The heat exchanger is also requested to have high reliability for gas leakage. The thermal cycle test of the heat exchanger has been performed and examined its reliability. The thermal cycle test apparatus is Fig. 8. The test was conducted by cooling the exchanger between room temperature and liquid nitrogen temperature. The test vessel in which test heat exchangers are put is immersed in liquid nitrogen and the heat exchangers are cooled to liquid nitrogen temperature. Then, the vessel moves to up and heat exchangers are heated up to room temperature by the heater. The temperature of the heat exchanger is measured by copper-constantan thermocouple. Also one thermal cycle between room temperature and liquid nitrogen temperature takes about 2 hours. During the test, high pressure and low pressure passages are pressurized with 1.57 MPa and 0.1 MPa helium respectively. Helium gas leakage flow is measured with a soap bubble flow meter attached to the low pressure side.

Table 1 summarizes results of the thermal cycle test. Before cooling the heat exchanger, helium gas leakage flow high pressure passages to low pressure passages was measured to be less than 1 X 10^{-4} Pa m^3/sec. After 235 cycles, helium gas leakage was constantly less than 1 X 10^{-4} Pa m^3/sec.

CONCLUSION

From these test results, it is confirmed that this heat exchanger can meet the requirements and fulfill the characteristics for " on-board refrigerator ".

A photograph of on-board helium refrigerator which we have developed is shown in Fig. 9. This refrigerator is Claude Cycle and consists of two reciprocating expantion engines and five laminated metal heat exchangers.

The refrigerator capacity is 5 W at 4.4 K. The size is 300 mm in diameter and 800 mm in length and the weight is about 40 kg. This refrigerator has been installed in the test vehicle and is presently being tested at Miyazaki Test Track in Japanese National Railways.

REFERENCES

1. R.B.Fleming, " A Compact Perforated-Plate Heat Exchanger " ; Adv. Cry. Eng., vol. 14, 197-204 (1968)

2. G.Vonk, " A Compact Heat Exchanger of High Thermal Efficiency " ; Philips Technical Review, vol. 29, no. 5, 158-162 (1968)

DISCUSSION

Question by W.L.Swift, Creare R&D; Have you tested shear strength, tensile strength and leakage of epoxy adhesive joints below liquid nitrogen temperature?

Answer by author; No, I have not.

Question by F.J.Kadi, Air Products & Chemical Inc.; Would you comment on any potential leakage of helium into vaccum space?

Answer by author; There is no leakage of helium into vaccum space, because headers and multilayer-body of heat exchanger are inserted into a thin walled stainless steel vessel.

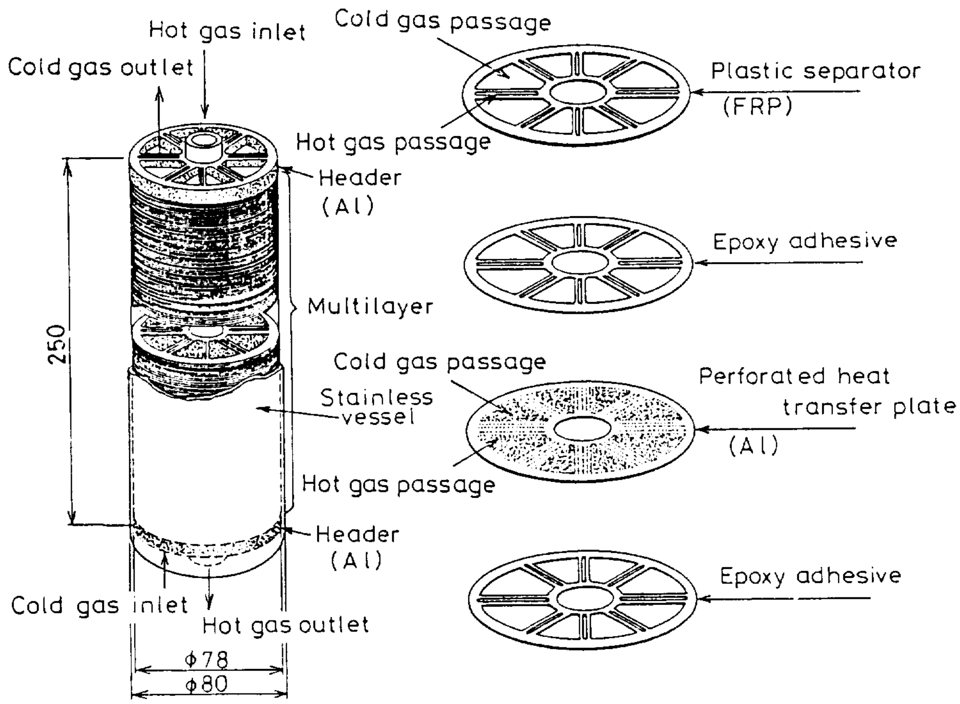

Fig. 1 The construction of laminated metal heat exchanger.

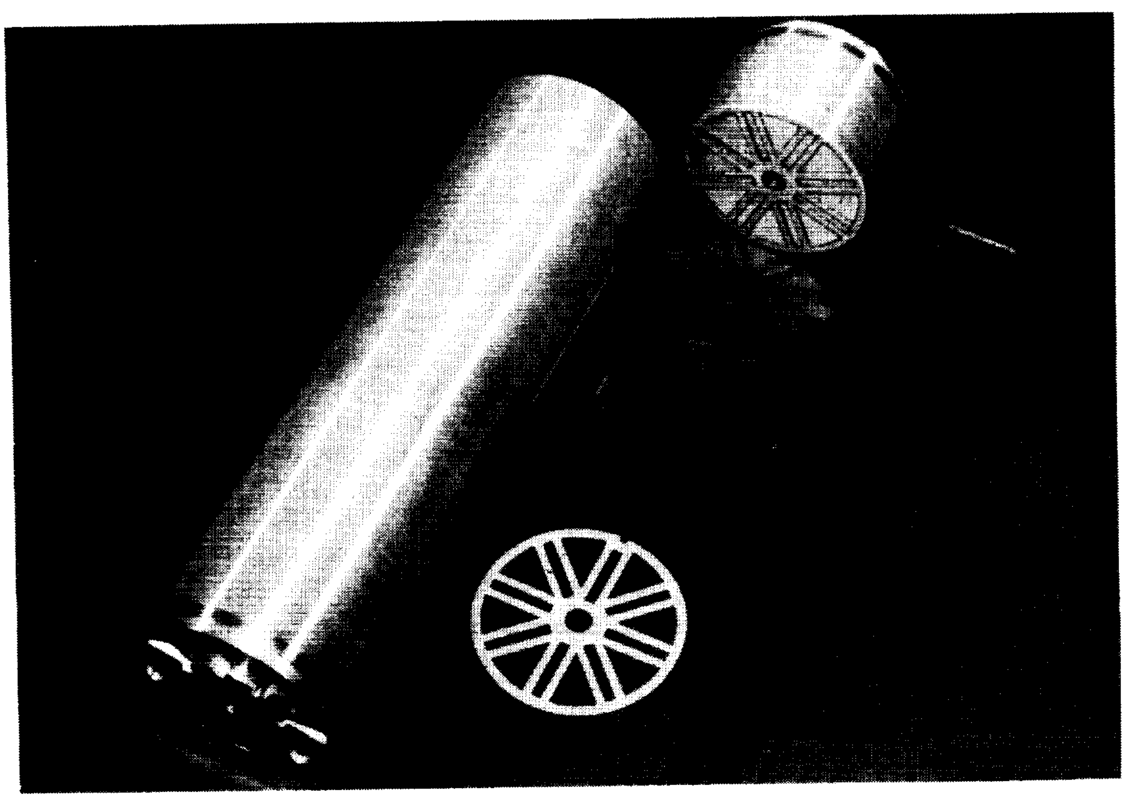

Fig. 2 laminated metal heat exchanger.

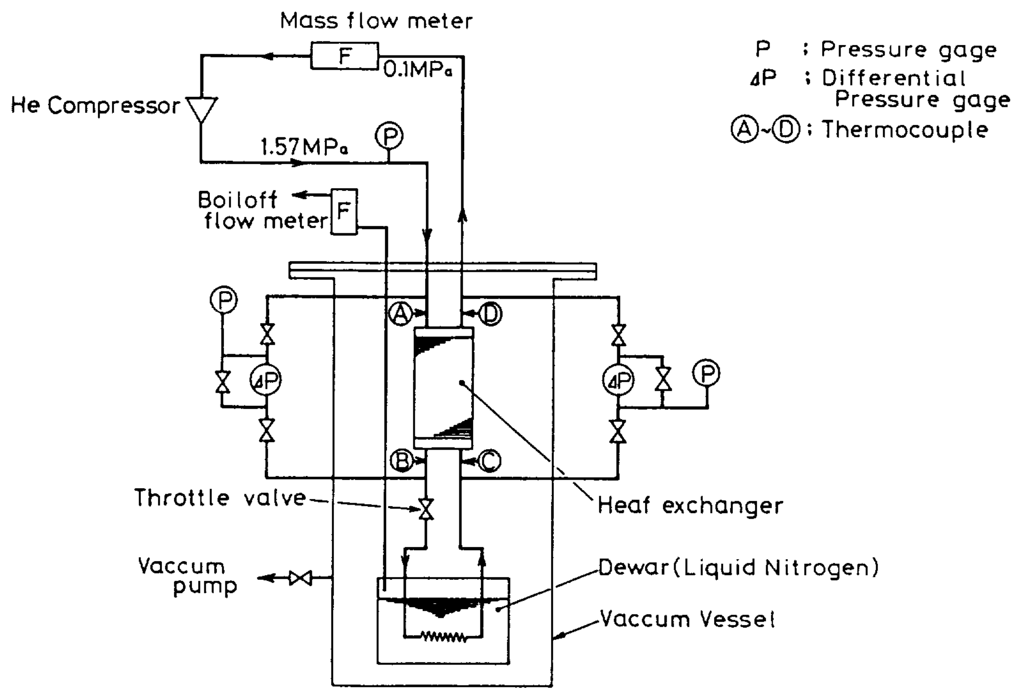

Fig. 3 Schematic diagram of heat transfer and friction loss performance test.

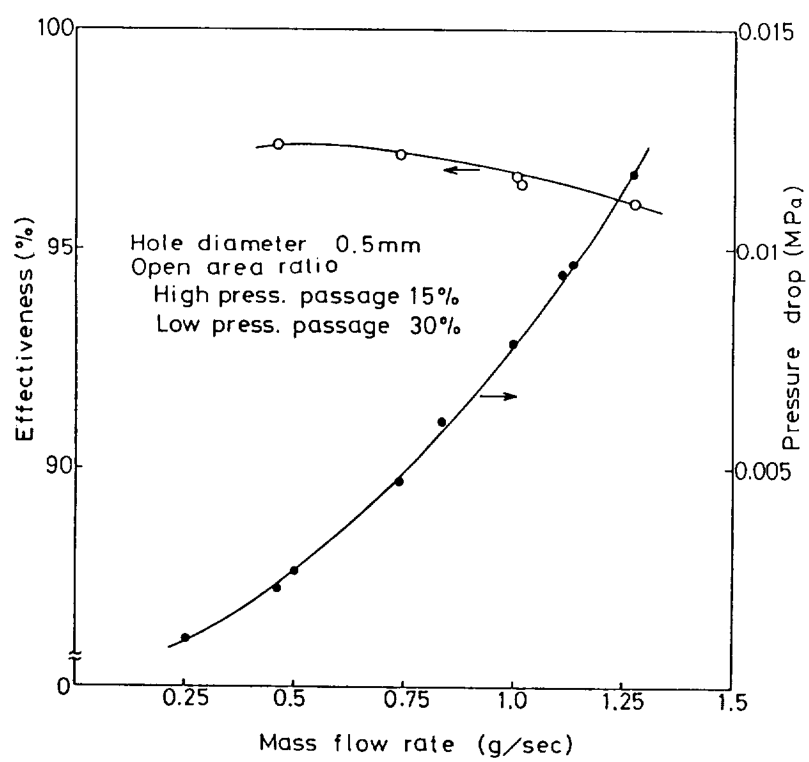

Fig. 4 Performance of laminated metal heat exchanger.

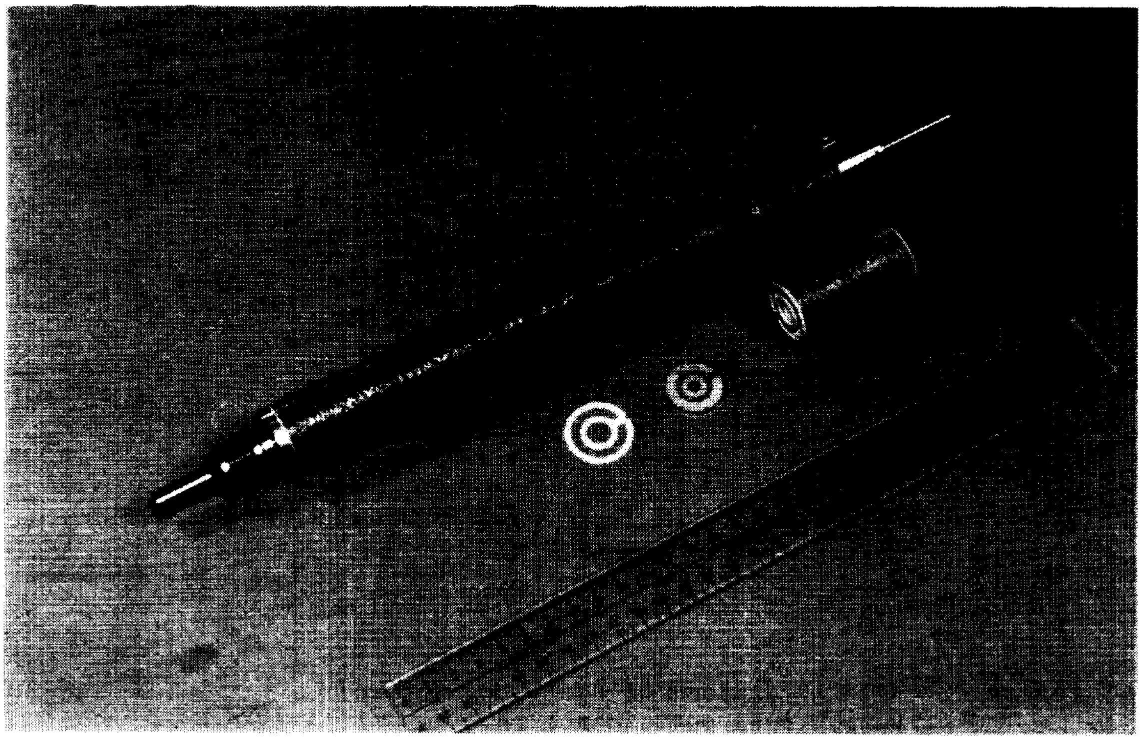

Fig. 5 Laminated metal heat exchanger.

Table 1. Result of thermal cycle test.

Item	Number of cycles	Pressure (MPa)		Helium gas leakage ($Pa\,m^3/sec$) (from high pressure passage to low pressure passage)
		High pressure passage	Low pressure passage	
Heat exchanger A	0	1.57	0.1	less than 1×10^{-4}
	235	1.57	0.1	less than 1×10^{-4}
		2.30	0.1	less than 1×10^{-4}
Heat exchanger B	0	1.57	0.1	less than 1×10^{-4}
	235	1.57	0.1	less than 1×10^{-4}
		2.30	0.1	less than 1×10^{-4}

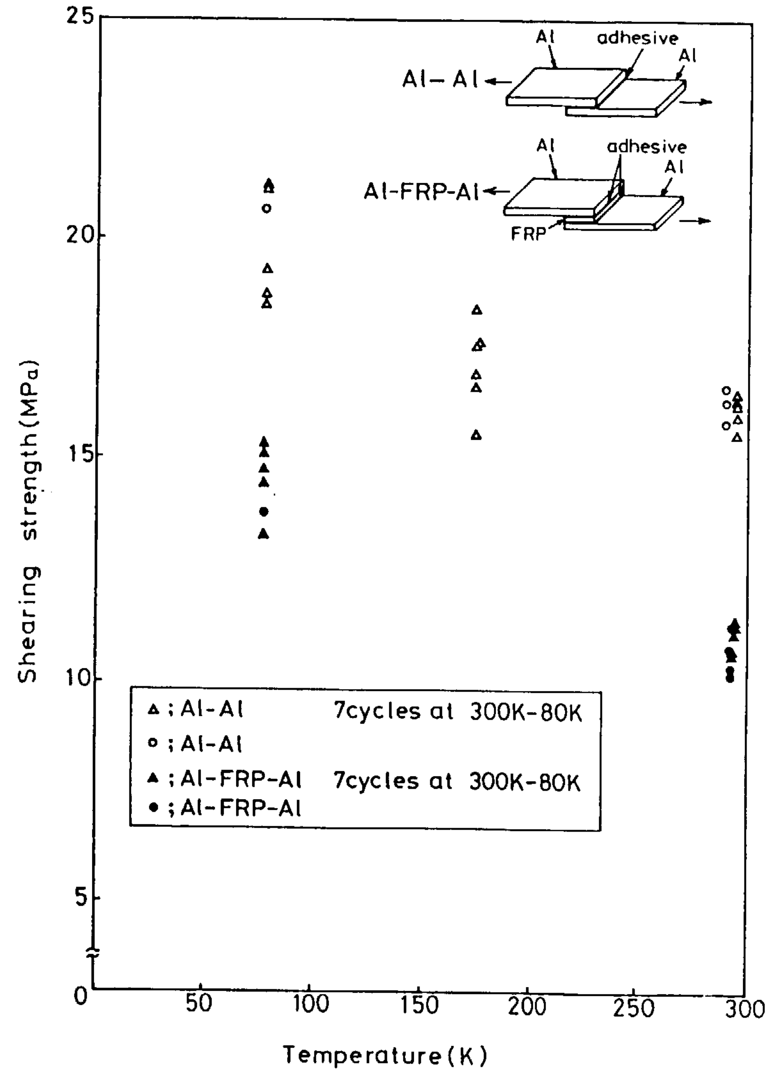

Fig. 6 Shearing strength of applied epoxy adhesive.

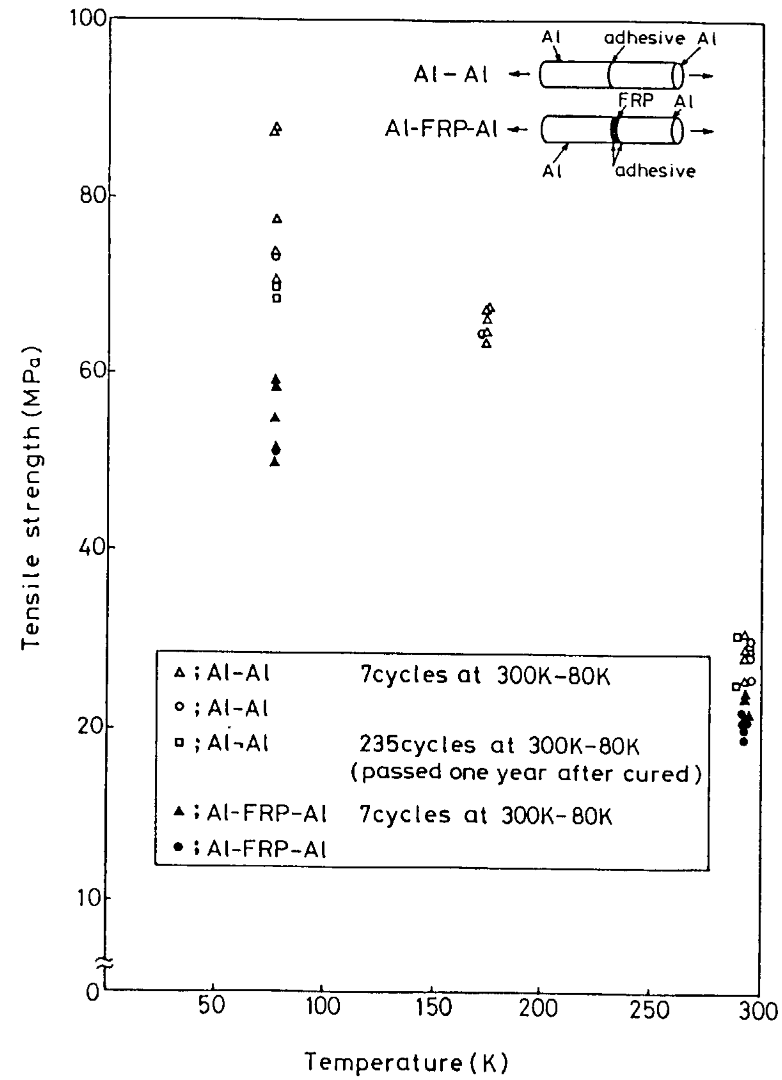

Fig. 7 Tensile strength of applied epoxy adhesive.

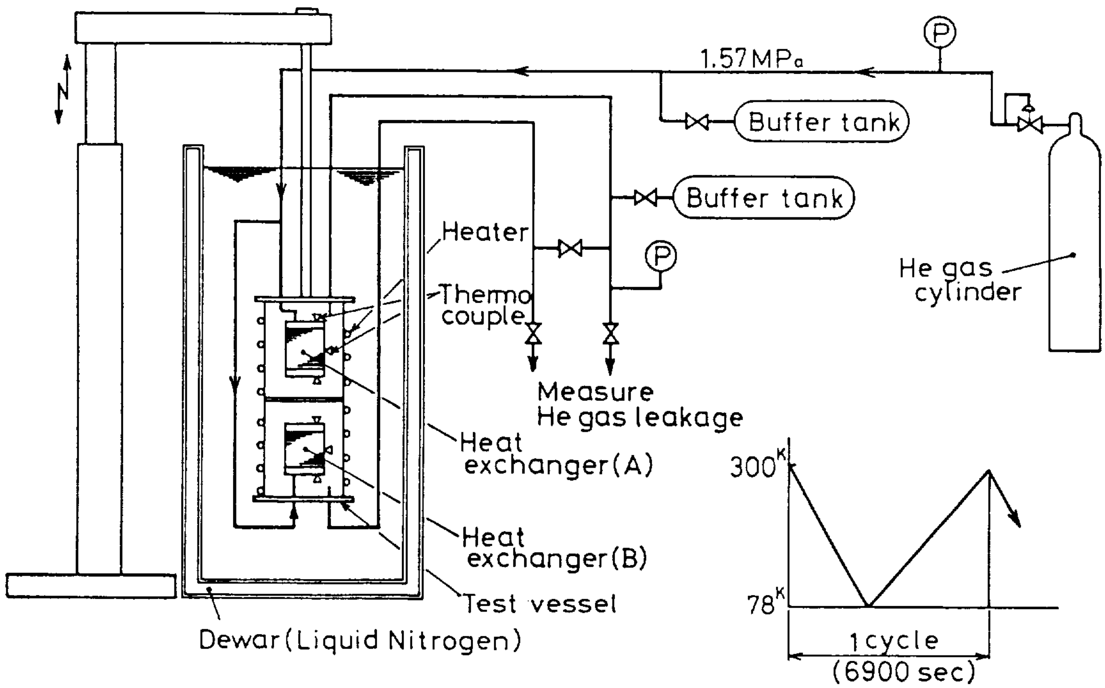

Fig. 8 Schematic diagram of thermal cycle test.

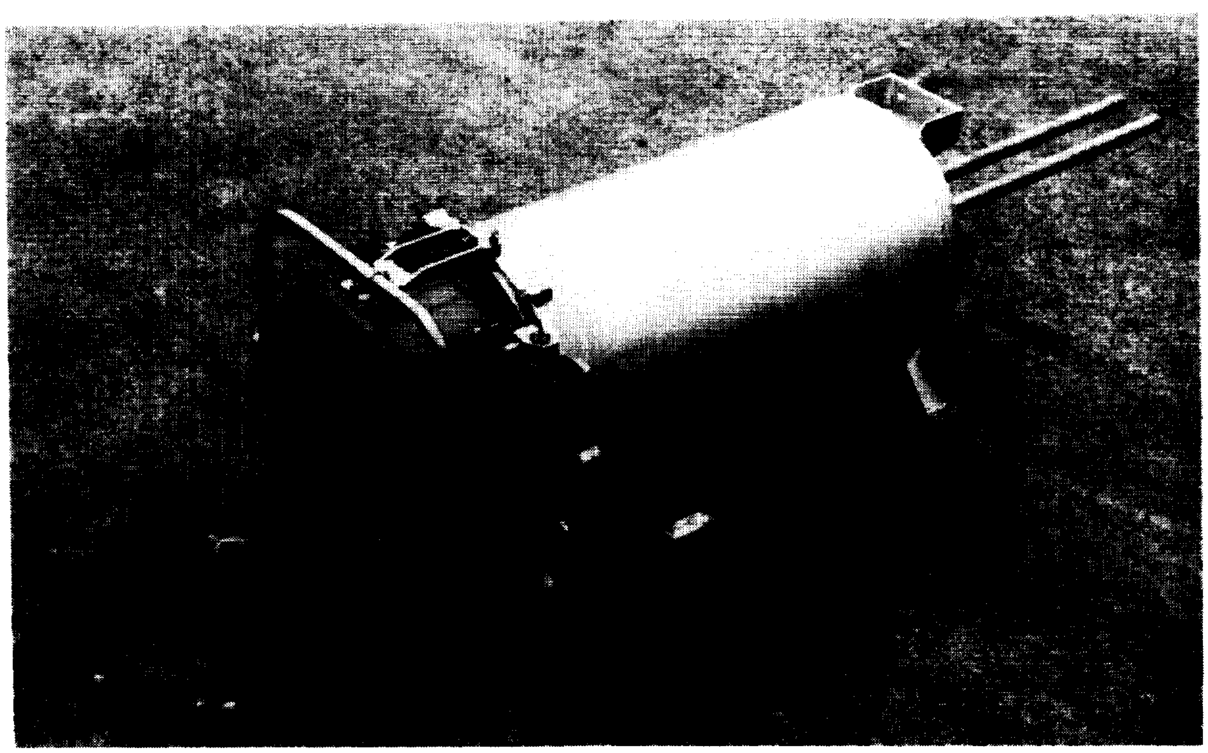

Fig. 9 Refrigerator