ADVANCES IN LOW-TEMPERATURE, CRYOGENIC, AND MINIATURE LOOP HEAT PIPES

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Abstract

Cryogenic, low-temperature, miniature, temperature-controlling, and other loop heat pipes (LHPs) with various working fluids are being developed at Thermacore, Inc. for existing and future applications. This paper presents LHP configurations and the test data obtained for three innovative loop heat pipes:

(a) Miniature LHP (the outer diameter of the LHP primary wick is 5.6 mm) with the temperature control utilizing a thermal-electric cooler (TEC),

(b) Cryogenic LHP operating in the temperature range from 65 K to 140 K using oxygen as a working fluid,

(c) Low-temperature LHP operating in the temperature range from 160 K to 280 K using ethane as a working fluid.

KEWWORDS

Loop heat pipe, thermal-electrical cooler, cryogenic, porous wick, ammonia, oxygen, ethane, temperature control

INTRODUCTION

While LHPs have become established two-phase systems used mainly in aerospace applications, there is a continuing effort to develop LHPs with various working fluids in order to cover all the temperature ranges encountered in the multiple applications. Miniaturization and economical temperature control are also high on the priority lists of LHP developers and users. This paper presents test data obtained for a miniature LHP with temperature control, a cryogenic LHP, and an LHP operating in a wide low-temperature range from 160 K to 280 K.

MINIATURE LHP WITH TEMPERATURE CONTROL

The miniature LHP with a stainless steel wick (5.6 mm outer diameter) used ammonia as a working fluid. The picture of the primary wick with the bubble pore radius of 1.2 ±0.2 micrometers is shown in Fig. 1(a). The image of the secondary screen-mesh wick (not to scale) is shown in Fig. 1 (b). The LHP configuration is shown in Fig. 2. It has a TEC installed on the compensation chamber and attached to a thermal link conducting the thermal energy, dissipated by the TEC, to the LHP evaporator. The LHP operating heat load range is from 1 W to 100 W. Its overall thermal conductance is about 5 W/K in the high-power range and much lower in the low-power range. One advanced feature of this miniature LHP is the temperature control utilizing the TEC, which can cool or heat the compensation chamber (with reversing the polarity) thus affecting the evaporator temperature. The effect of the TEC cooling the compensation chamber is shown in Fig. 3, where the LHP operated at the heat load of 5W with the evaporator elevated by 15 cm above the condenser. Turning on the TEC with the power consumption of about 1 W reduced the evaporator temperature by more than 3°C. Reversing the TEC polarity and adjusting its power consumption allows to elevate the evaporator temperature and maintain it

at a pre-determined level in a situation with dynamic environmental conditions and varying heat dissipation from the cooled component as discussed in [1].

CRYOGENIC LHP WITH THE TEMPERATURE RANGE FROM 65 K TO 140 K

The cryogenic LHP configuration presented earlier in [2, 3] is shown in Fig. 4 and the thermocouple locations are given in Fig. 5. The LHP has three additional components compared to the conventional LHP configuration: (1) secondary capillary pump hydraulically linked to the main condenser, (2) additional condenser, and (3) a pressure reduction reservoir. It is capable of cooling down from the supercritical temperature of the working fluid (oxygen, nitrogen, etc.) with only the condenser end being cooled and operating with the environment at room temperature and the main evaporator elevated versus the condenser end. The LHP parameters are listed in Table 1.

Table 1: Significant parameters of the cryogenic LHP

Wick Material	Stainless Steel	**Liquid Line OD**	2.4 mm
Wick Pore Radius	2.4 microns	**Serpentine Condenser Line OD**	3 mm
Wick Permeability	5×10^{-14} m^2	**Main Condenser OD**	6 mm
Evaporators OD	20 mm	**Main Condenser length**	140 mm
Wick Heated Length	20 mm	**Volume of the Pressure Reservoir**	300 cm^3
Vapor Line Length	600 mm	**Dimensions of the Cold Plate**	44×140 mm^2
Vapor Line OD	3 mm	**Secondary wick screen mesh**	300 mesh

The LHP with the additional capillary pump at the cold end to facilitate cooling down from the supercritical conditions prior to startup of the main evaporator has been successfully demonstrated using oxygen as a working fluid. The main and additional condensers were cooled using a cryocooler. Typical test data are shown in Fig. 6 for the horizontally oriented LHP filled with oxygen. The LHP was tested in a vacuum chamber with the temperature-controlled shrouds. The test data in Fig. 6 were obtained for the shroud temperature of about -50°C. The LHP also started and operated with the shroud temperature above 0°C as presented in [1]. This particular configuration has two transport lines unlike the configuration with three transport lines presented in [4]. The results of the testing can be summarized as follows.

1. The LHP reliably and predictably started in multiple tests and operated with the heat load range at the main evaporator from 0.5 W to 9 W with zero power on the secondary evaporator.
2. The LHP operated with the evaporator temperature of about 75 K (-198°C) with the shroud temperature of approximately 170 K (-110°C±10°C) and at 100 K (-170°C) with the shroud temperature of approximately 290 K (20°C) while the cold block temperature was 70 K (-203°C). The evaporator and condenser thermal resistances of the LHP were sufficiently low.
3. The LHP transported 9 W with the main evaporator elevated versus the condenser by 5 cm
4. The LHP reliably started and operated with the shrouds at room temperature and elevated main evaporator

LOW-TEMPERATURE LHP WITH THE TEMPERATURE RANGE FROM 160 K TO 280 K

The low-temperature LHP using ethane as a working fluid and its parameters were first presented in [5]. The LHP picture is given in Fig. 8. It demonstrated excellent thermal performance four years after it was processed and filled with ethane. The presented LHP used a nickel wick with the bubble pore radius from about 6 micrometers. While the lowest temperature in the test data shown in Fig. 8 is about -70°C, LHPs with ethane as a working fluid developed at Thermacore, Inc. reliably operate in the wide temperature range from 160 K to 280 K.

Figure 1: Primary (a) and secondary (b) wicks of the miniature LHP

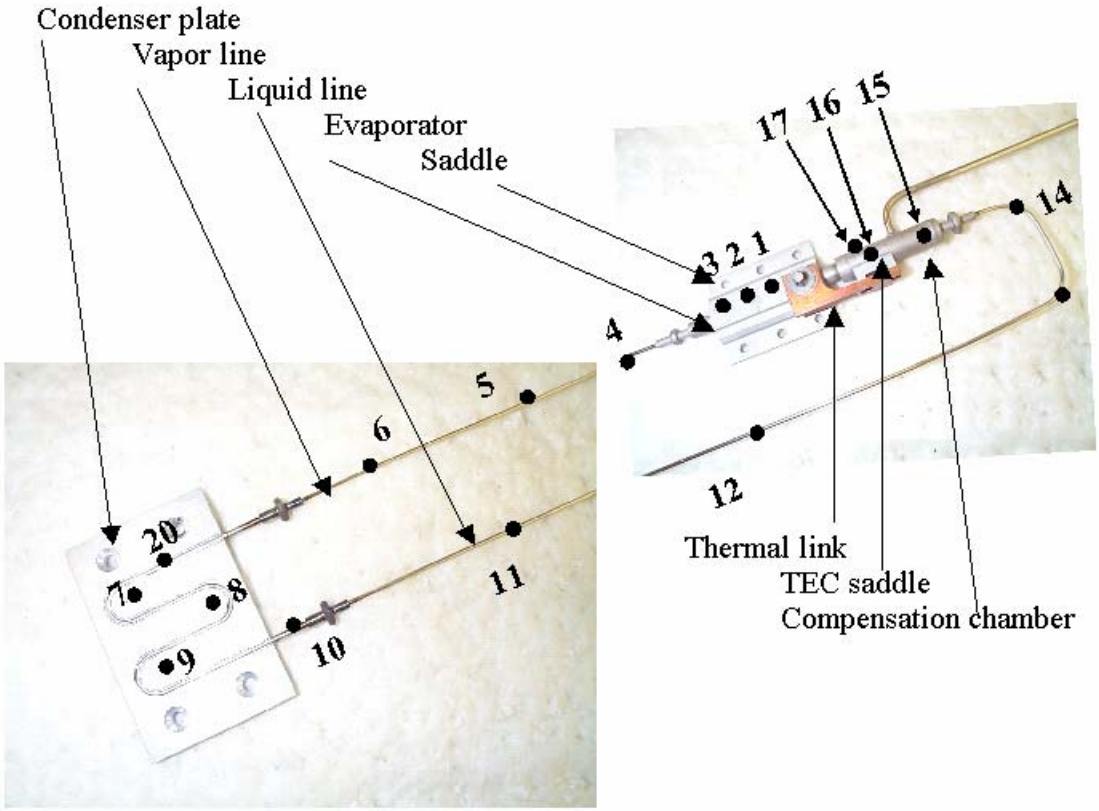

Figure 2: Configuration of the miniature LHP with the thermocouple locations

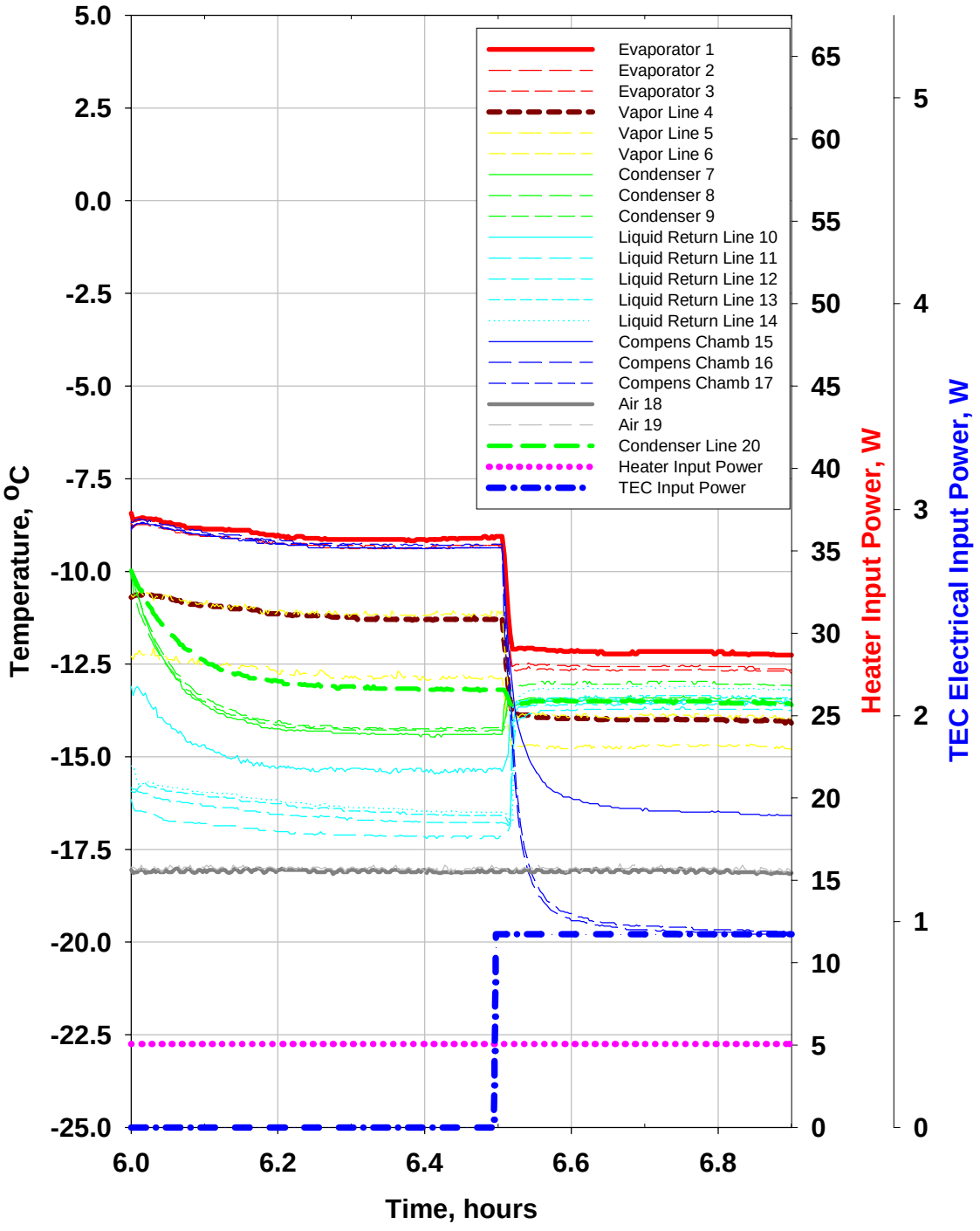

Figure 3: Effect of the TEC cooling on the evaporator temperature of the miniature LHP with the evaporator 15 cm above the condenser

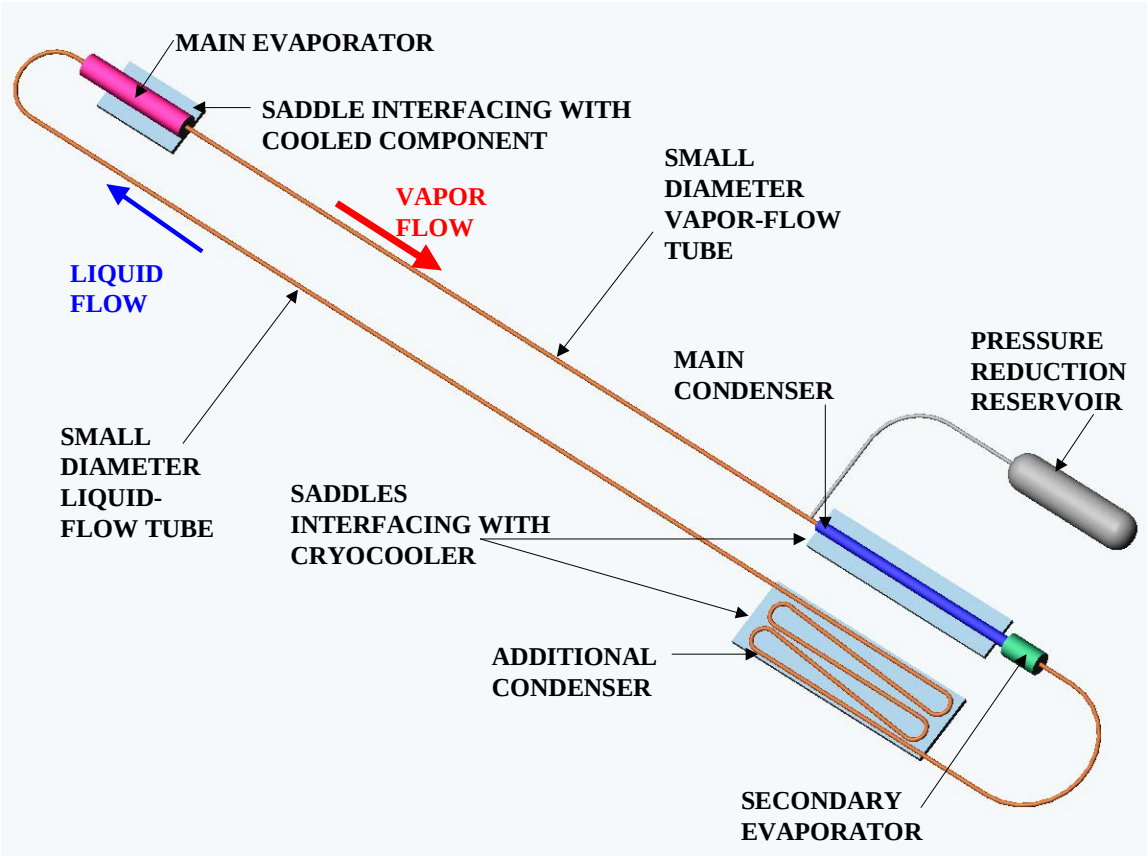

Figure 4: Configuration of the cryogenic LHP

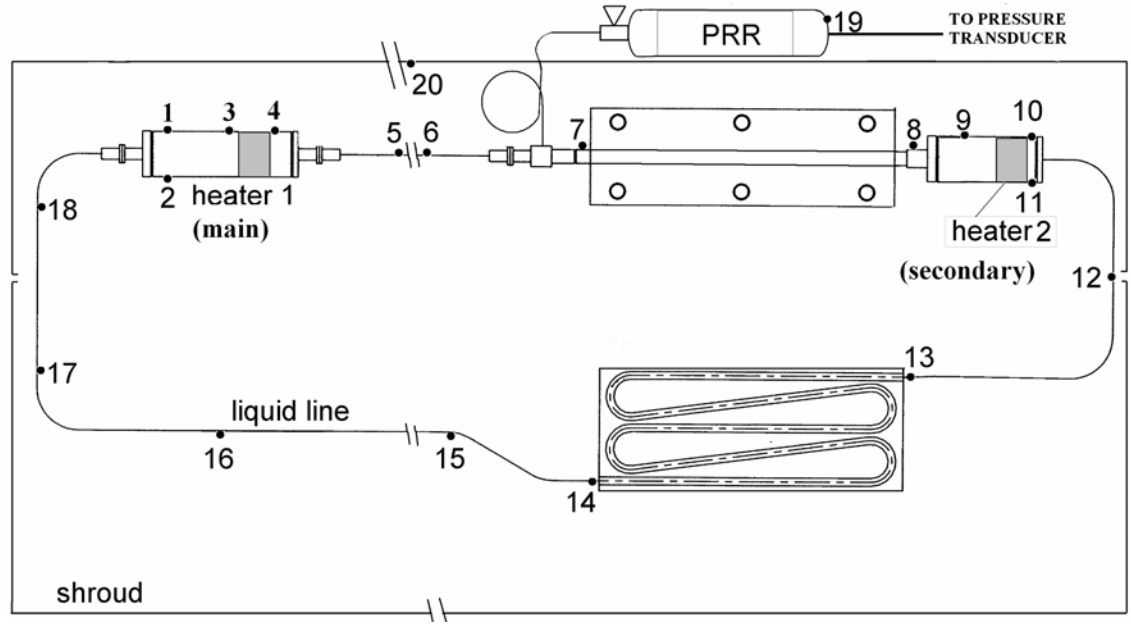

Figure 5: Thermocouple locations for the cryogenic LHP test

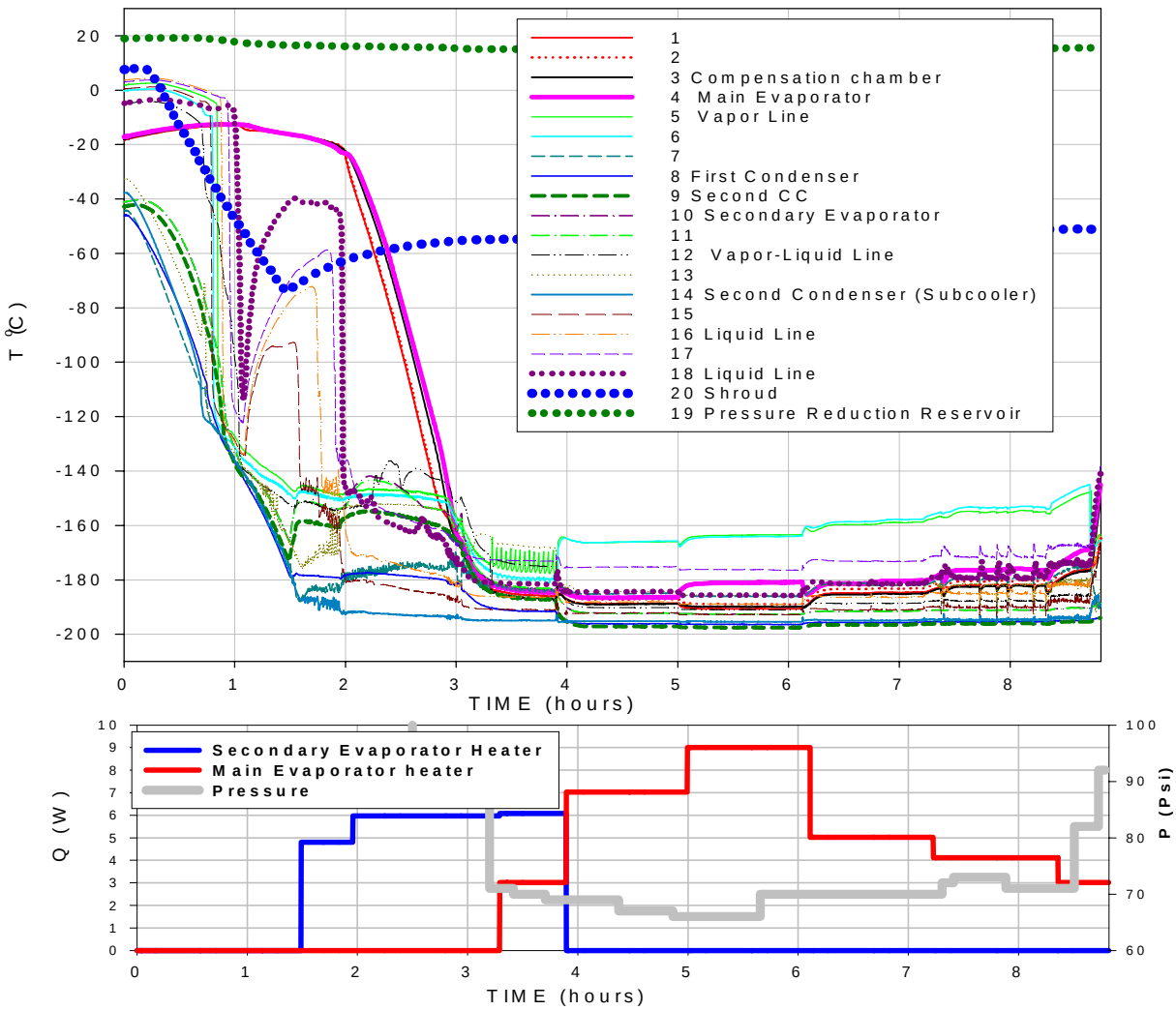

Figure 6: Cooling down, startup and operation of the cryogenic LHP using oxygen as a working fluid with the environment temperature at -50°C

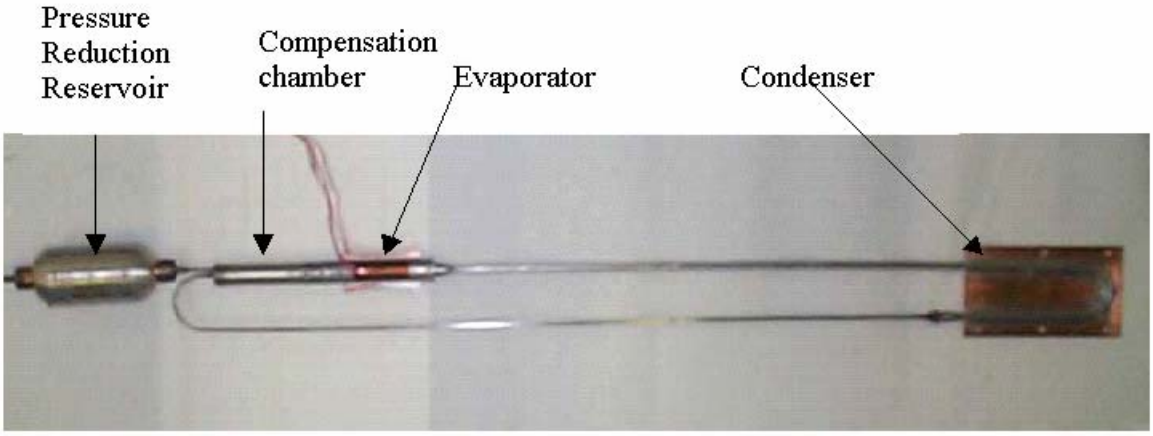

Figure 7: Picture of the ethane LHP tested in an environmental chamber with forced-air convection cooling

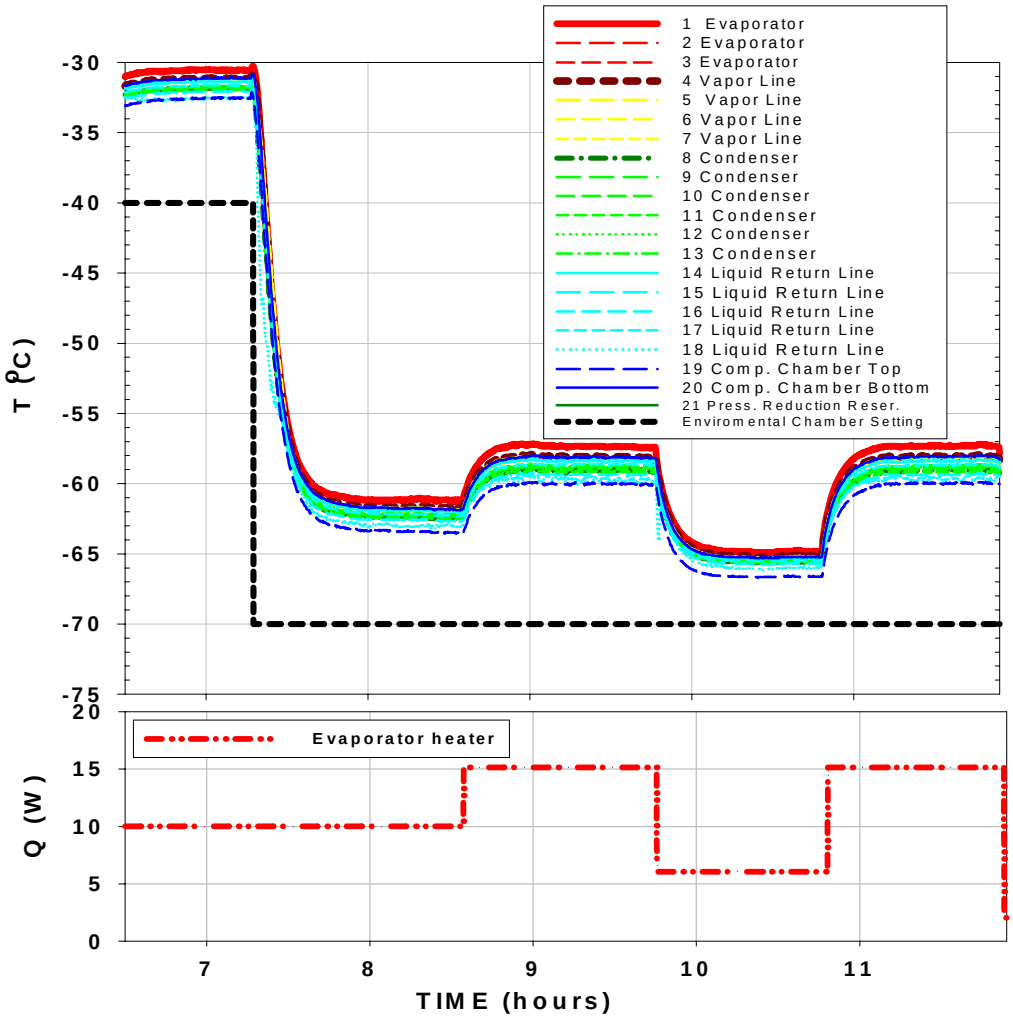

Figure 8: Test data obtained for the ethane LHP tested in an environmental chamber with forced-air convection cooling

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