

Termosyphon cryogenic system for RED-100 detector

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Abstract. A cryogenic system based on a two-phase closed tubular termosyphon with 12 mm diameter copper tube is developed. It was used for thermal stabilization of the liquid xenon emission detector RED-100. The nitrogen refrigerant cooled down with a free-boiling liquid nitrogen bath has been used. It was shown that the system supports the RED100 operation at temperature 166 K with accuracy ± 1 K.

1. Introduction

1.1. About RED 100

The RED 100 emission detector based on liquid xenon is being created by the efforts of the RED (Russian Emission Detectors) collaboration for detecting and investigating the effect of coherent neutrino scattering off heavy nuclei. The principle of registration was discussed in detail in the paper [1]. Such a detector can register single electrons produced in massive active medium from rare ionizing interactions with low-energy signature.

1.2. Challenges for cryostatting system

The RED 100 detector contains 200 kg of liquid xenon in a 100 kg titanium cryostat. The total mass of the detector including xenon, cryostat, PMTs and internal light-collecting structure is about 500 kg. The challenge for the cryogenic system is to condense xenon and to maintain a constant temperature in the liquid at about 166K with an accuracy of 1K during long time required for the experiment. The additional challenges are:

- 1) Minimizing the mass of peripheral devices near the detector.
- 2) Deposition of the detector inside a massive defence or in a deep well for providing low-background experiment.

The last requirement means that the detector should be removed to a distance of several meters from the data acquisition system, gas purifying system and cryostatting systems for the detector. The described termosyphon technology meets the specified requirements.

2. Termosyphon principle of operation

The termosyphon or gravity-assisted heat pipe consists of three basic sections shown in figure 1: a cooling section (condenser) located above a heating section (evaporator) and a passive adiabatic section connecting the two active sections [2].



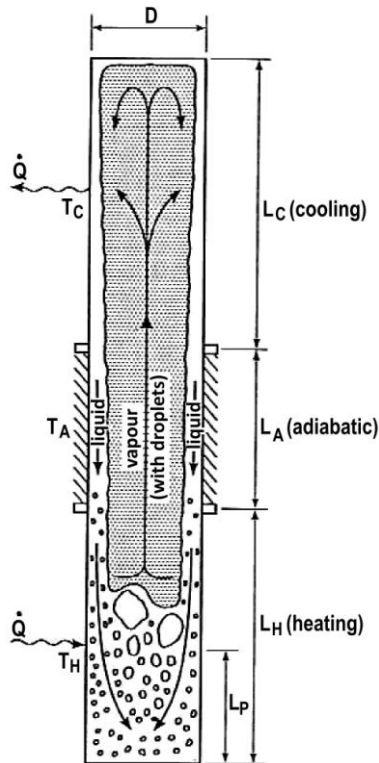


Figure 1. The operating principle of a two-phase closed tubular thermosyphon (heat pipe).

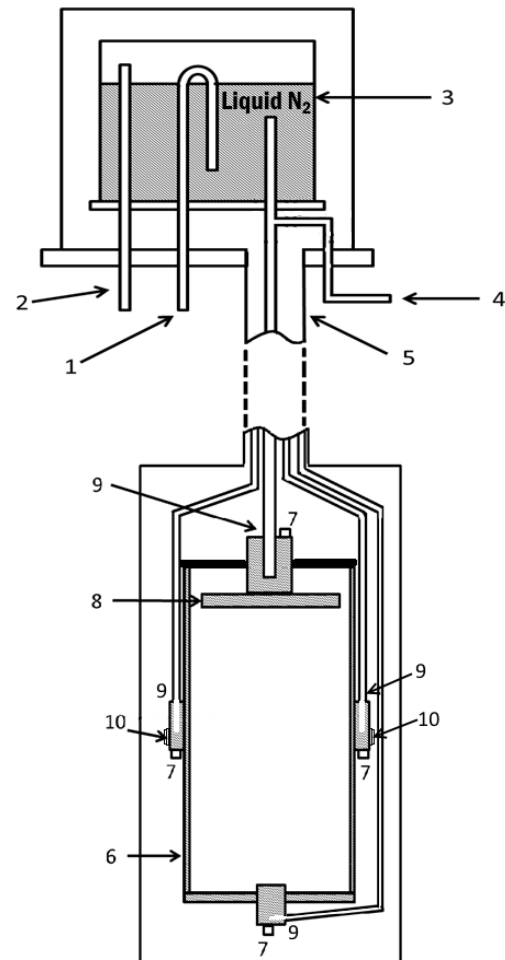


Figure 2. Schematic drawing of the experimental setup: 1 – liquid nitrogen inlet; 2 – ventilation outlet; 3 – liquid nitrogen tank; 4 – nitrogen fluid supply from charging system; 5 – vacuum jacket; 6 – copper roll; 7 – thermal resistors Pt-100; 8 – copper condenser; 9 – evaporators; 10 – heaters.

The condenser of LC length is filled with gas, which is depositing heat energy Q into a cooling machine operating in a good thermal contact with this section. The condensate generated inside the condenser falls down through the adiabatic section into the evaporator, where the liquid is boiling and absorbing the heat Q . The generated vapor is rising up into the condenser, returning the heat to the cooling machine, condensing in the liquid phase, then, the heat transfer cycle repeats. Since the operation of the thermosyphon relies upon the gravitational force, the evaporator must be located below the condenser. The schematic drawing of the experimental setup is shown in figure 2.

3. Thermal stabilization system

Two types of thermosyphon was considered. The first one is a bellow flex hose thermosyphon consist of standard high-vacuum stainless steel bellow hose with 1/2" inside diameter with the same cooling and heating sections as reported in [3]. The other one is a closed tubular thermosyphon consist of 12 mm diameter copper pipe. A comparison of the operation for these two types is shown in figure 3.

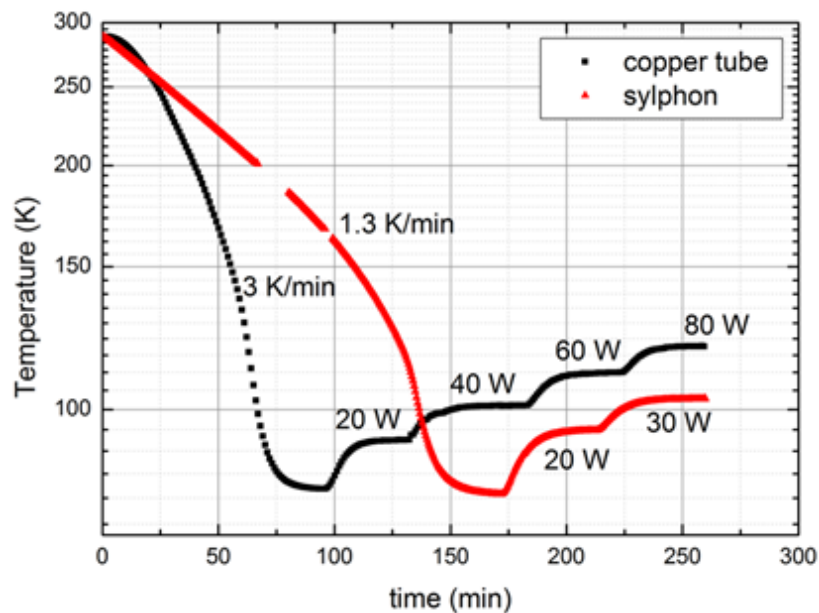


Figure 3. Temperature-time dependences both for copper pipe (black line) and for bellows flex hose thermosyphon (red line). The error bars are within data points.

Figure 3 shows the temperature of the cold head under different heat load conditions. At the beginning of the test, the thermosyphon is vacuumed at room temperature. The cooling power is applied to the cold head via the evaporator as soon as the thermosyphon is charged with nitrogen fluid. When the lowest temperature 80 K is achieved, the additional electric power is applied with the electrical heater (15 Ohm, 200 W resistor) installed on the cold head. The temperatures rise with the increase of the heat load. The steady states are observed at different heat powers.

From this comparison we conclude that the thermosyphon based on copper tube has an advantage, because it has larger cooling capacity.

In order to maintain a constant temperature it was used an automatic control system which regulates the amount of nitrogen in the thermosyphons. The algorithm of the automatic control system is as follows:

- 1) Turn on the thermosyphon. The injection valve which providing nitrogen from an external gas source into the heat pipe is opened for a time Δt_1 ;
 - 2) The temperature of the heat exchanger reaches $T_0 - \Delta T$;
 - 3) Turn off the thermosyphon. The relief valve which connect heat pipe with atmosphere is opened for a time Δt_2 ;
 - 4) The heat exchanger temperature begins to rise and reaches $T_0 + \Delta T$ due to the external heat;
 - 5) The injection valve is opened again for the period Δt_1 and the cooling cycle is repeated.
- Constants Δt_1 , Δt_2 are selected empirically for each thermosyphon individually.

4. System launching

The result of the cryotest for copper pipe is shown in figure 4. The red line corresponds to the side of the detector, and the black line – to the bottom. The graph has two plateaus, corresponding to different temperatures stabilize. It was shown that we can maintain a constant temperature of the detector at 166 K with an accuracy of 1 K.

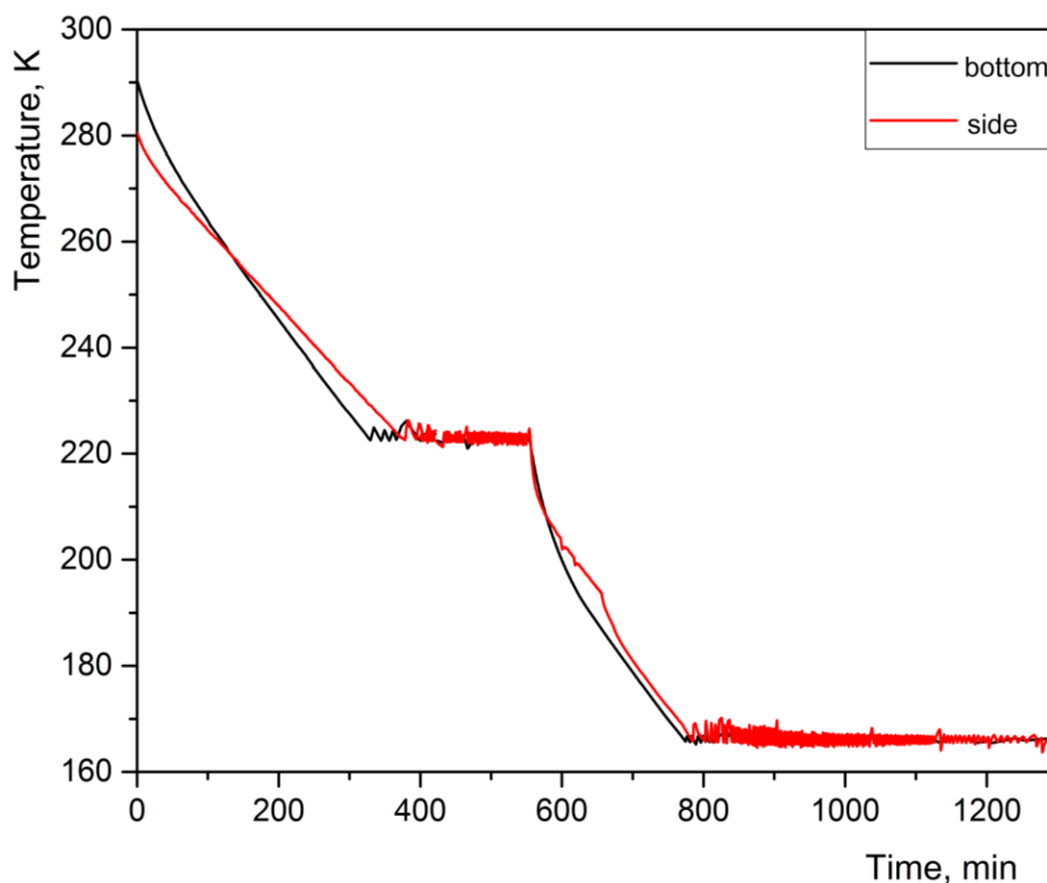


Figure 4. Dynamic temperature stabilization using the copper pipe thermosyphons for bottom and side of the detector. The error bars are within data points.

5. Conclusion

It was shown that the cryogenic system based on closed two-phase thermosyphon using nitrogen as an active medium can provide thermal stabilization of emission detector based on liquid xenon at required temperature with an accuracy of 1K. Such a system was investigated and successfully tested.

Acknowledgements

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References

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