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Calibration of Temperature Probes on Heat Pipes

Jacques-Olivier FAVREAU[1]*, Eric GEORGIN*[2]*,*
[1] *CETIAT, 25 avenue des arts 69100 VILLEURBANNE FRANCE,*
Jacques-olivier.favreau@cetiat.fr

Summary:

For the past ten years, CETIAT has been working on the development of a new type of temperature generator. The goal is to reduce the stabilization time at calibration temperatures while ensuring an exceptional thermal quality of the comparison medium.

Heat pipe-based temperature generators are studied in several metrology institutes, such as INRIM and LNE. While water-based heat pipes have already been the subject of extensive research, the innovation introduced by CETIAT lies in the development of an ethanol-based heat pipe. This breakthrough enables coverage of a temperature range suitable for industrial calibrations, from -30 °C to 120 °C. This is made possible by combining two heat pipes: one using water and the other ethanol. These heat pipes are GCHPs: Gas-Controlled Heat Pipes.

The use of a heat pipe for calibrations at negative temperatures represents a first in metrology. In 2024, this calibration method was accredited by COFRAC. This article provides a summary of the results obtained and the calibration possibilities offered by this innovative technology.

Keywords: GCHP, Heat pipe, Calibration, metrology

1. Why use heat pipes as a comparison medium?

Heat pipes offer two major advantages: exceptional thermal homogeneity and robust, rapid implementation. The heat pipe effect relies on the liquid-gas phase change of a fluid, governed by Clapeyron's law. This phenomenon ensures an extremely stable phase transition temperature. The energy supplied to the system is absorbed during this phase transition, thus limiting the influence of external disturbances. When a heat pipe is connected to a regulated pressure circuit, it becomes possible to continuously adjust the temperature setpoints, as the adjustment parameters are temperature and pressure.

2. Operation of a heat pipe in metrology

The heat pipe effect is based on the liquid-to-gas phase change of a fluid. Clapeyron's law defines this phase change, which is extremely stable.

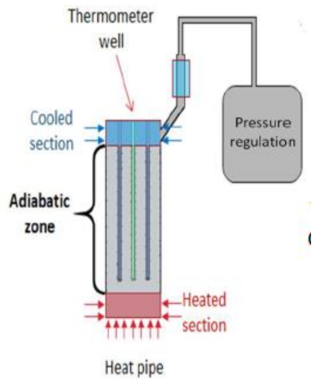

Fig. 1. Principle Diagram of the Heat Pipe Effect

A metrological heat pipe takes the form of a sealed cylinder. At its base, a fluid is heated and evaporates (evaporator). The resulting vapor condenses on a cooled upper surface (condenser), before flowing back by gravity to the evaporation zone. Between these two areas, a nearly adiabatic central region provides remarkable thermal homogeneity, making it ideal for calibration applications.

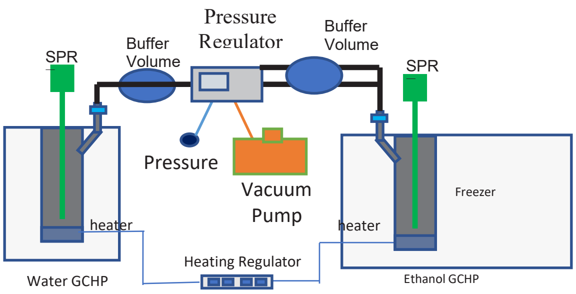

Fig. 2. Principle Diagram of the CETIAT GCHP

Compared to an overflow thermostat bath, the heat pipe offers superior thermal performance due to this effect. Additionally, regulation is provided by a pressure control system, which is more responsive than a traditional resistive device, allowing for quick adjustments of setpoints on heat pipe-based generators (GCHPs). Once the temperature and pressure conditions are defined, the heat pipe effect is established in a highly reproducible manner.

3. Adaptation to Calibrations

To transform a heat pipe into a temperature generator for calibrations, it is necessary to add inserts (heat sinks) for inserting the probes to be calibrated, like dry block ovens. Although the sensors are not directly immersed in a heat transfer fluid, as they would be in a calibration bath, the impact is negligible thanks to the excellent thermal characteristics of the heat pipe. Moreover, this setup also allows for the calibration of non-immersible sensors, provided their diameters are compatible.

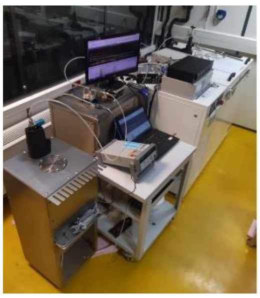

Fig. 3. Photo of the CETIAT GCHP.

The GCHPs are thus ideal candidates for the realization of automated calibrations, combining precision, speed, and robustness.

4. Description of the Heat Pipes

The water-based heat pipe consists of a stainless-steel cylinder with a diameter of 114 mm and a length of 440 mm, featuring internally grooved walls. It is equipped with a removable lid that includes seven inserts (heat sinks) for inserting the sensors to be calibrated. These inserts, 400 mm in length and with an internal diameter of 10 mm, are particularly suited for calibrating long-stem reference probes such as SPRTs.

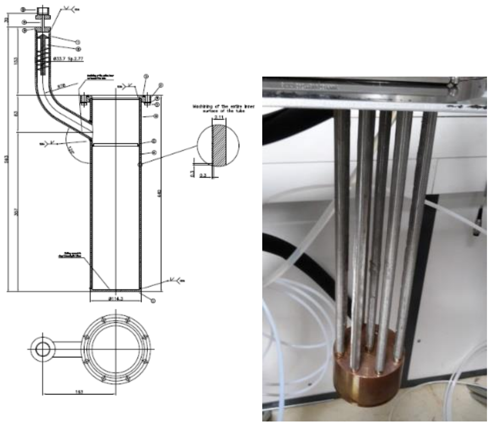

Fig. 4. Photo and diagram of the heat pipe

The walls immersed in the heat pipe are covered with a metallic wick that allows the flow of the condensate. A "gel tube" type cooling system maintains a constant temperature at the condenser throughout its use. The only variable parameters are the heating temperature at the evaporator and the pressure applied to the heat pipe. The pressure setpoint allows for precise definition of the internal temperature of the heat pipe, thanks to a pre-established pressure-temperature curve. Once configured, this system is easy to use.

Pressure regulation is achieved by a high-precision regulator, the Pace 6000, allowing adjustments to the nearest pascal. By knowing the pressure-temperature relationship, it becomes possible to quickly reach the desired temperature with excellent stability, making the heat pipe an ideal medium for calibrations.

5. Characterization of the GCHP

The two heat pipes at CETIAT have been characterized thermally according to the best current practices for characterizing temperature generators, including the use of a calibration bath. This characterization was carried out using reference thermometers, calibrated within the laboratory. We analysed the homogeneity and stability of the working volume over a period of at least 30 minutes, after the thermal steady state was established. The thermal load allowed us to evaluate the heat pipe's ability to compensate for the effect of a significant thermal load, such as the simultaneous calibration of six thermometers. Although the results obtained are lower than those from the National Metrology Laboratory

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due to the traceability of the thermometers used, they still allow for an improvement in calibration uncertainty, reducing it from 0.03 °C to 0.02 °C.

Result /°C	Water	Ethanol
Homogeneity	0.001	0.005
Stability	0.003	0.009
Thermal loads	0.001	0.003

Fig. 5. Performance of the CETIAT GCHP.

6. Temperature Ranges and Innovations

The water-based heat pipe covers a temperature range from +30 °C to +120 °C. To extend this range, CETIAT has developed an ethanol-based heat pipe, a first in the field. This heat pipe is installed in a freezer maintained at a constant temperature of -80 °C, ensuring an ambient temperature lower than the operating temperature. This configuration allows the ethanol-based heat pipe to function effectively in a range of negative temperatures.

The thermal performance of the ethanol-based heat pipe is comparable to that of the water-based heat pipe. Together, these two devices provide CETIAT with high-quality metrological comparison media, covering a temperature range from -30 °C to +120 °C.

7. Validation and Implementation

The method was validated through an inter-laboratory comparison conducted with other laboratories accredited by COFRAC according to ISO 17025, with uncertainty levels that are closely aligned. The results showed a normalized deviation of less than 1, confirming the reliability of the method. In 2024, this approach was officially accredited by COFRAC.

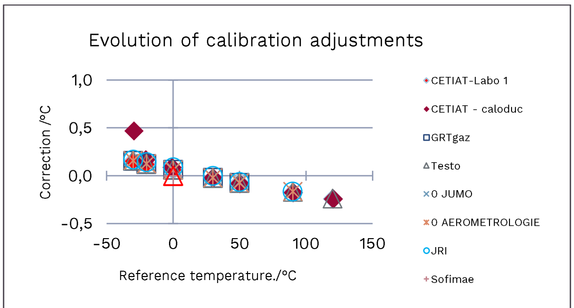

Fig. 6. *Results of the inter-laboratory comparison*

Today, CETIAT is able to perform temperature calibrations with an uncertainty of 0.02 °C. Initially, these calibrations will be reserved for internal use to allow laboratory technicians to gain expertise and experience. Ultimately, this expertise will be extended to commercial calibration services.

8. Conclusion

The implementation of pressure-regulated heat pipes as a comparison medium for temperature calibrations has been at the heart of extensive research, particularly in national metrology laboratories in France, Italy, and other countries. For the first time, CETIAT has developed a heat-pipe-based temperature generator intended for industrial calibrations.

To meet the needs of commercial calibrations, CETIAT has also innovated by designing a heat pipe capable of operating at negative temperatures, a first. This system relies on the integration of an ethanol-based heat pipe in a freezer, thereby opening up new possibilities.

The ongoing optimization of uncertainty budgets will ultimately allow for the offering of commercial calibrations with significantly reduced uncertainty levels compared to current solutions. Moreover, CETIAT is actively committed to promoting this type of high-quality generator, while highlighting its ease of use.

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