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Effect of bushings in thermometric fixed-point cells

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ABSTRACT

Bushings are tubular inserts that can be used with temperature fixed-point cells for the calibration of standard platinum resistance thermometers in accordance with the International Temperature Scale of 1990. They are made out of different materials such as glass and various metals with high thermal conductivities. Their function is to increase the thermal contact between the thermometer's sensor and the phase boundary in the thermometer well of the cell. In the paper, the effect of bushings on the self-heating and on the immersion profiles of thermometers in fixed-point cells was researched. Three different thermometers were used: one fused silica sheathed and two Inconel sheathed. The self-heating was measured in the temperature range from the mercury triple-point to the zinc freezing-point with and without metal bushings: brass, aluminum and copper. The immersion profiles were measured in the zinc cell with and without an aluminum and a glass bushing. Besides experimental measurements, some qualitative results of numerical modeling are also presented. The bushings considerably lower the self-heating, in some cases even by more than 50%. But, on the other hand, bushings seem to increase the measured temperature, worsen the immersion profile and act as a radiation shield in the gap between the thermometer and the fixed-point cell at higher temperatures, where radiation is the dominant mode of heat transfer.

1. Introduction

Standard platinum resistance thermometers (SPRTs) are interpolation instruments for the determination of the temperature t_{90} in the range between −259.3467 °C and 961.78 °C in accordance with the International Temperature Scale of 1990 (ITS-90) [1]. There are two types of protection sheaths for long-stem SPRTs: fused silica sheaths and Inconel sheaths. These thermometers are calibrated in temperature fixed-point cells: triple, melting and freezing-point cells of pure substances. For this paper, the relevant temperature range is from −38.8344 °C to 961.78 °C. The defining fixed-points in this range are collected in Table 1.

During calibration, a SPRT is inserted in the thermometer well of the cell which is immersed in the fixed-point substance undergoing the phase transition as shown in Fig. 1. In case of metal freezing-point cells, the metal is contained in a graphite crucible and the thermometer well is not in direct contact with the metal. The thermometer wells of mercury triple-point cells are usually filled with ethanol as a "contact liquid" that fills the space between the SPRT and the well. With water triple-point and gallium melting-point cells, distilled water instead of ethanol is used. With metal freezing-point cells (indium, tin, zinc, aluminum and silver), there is normally no contact liquid and air fills the space between the SPRT and the well. The thermal conductivities of these materials are quite low. In order to increase the thermal contact between the SPRT and the phase boundary, a bushing made out of thermally conductive material can be used, such as aluminum.

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Table 1
Relevant ITS-90 fixed-points [1].

Fixed-point	t_{90}/°C
Mercury triple-point	−38.8344
Water triple-point	0.01
Gallium melting-point	29.7646
Indium freezing-point	156.5985
Tin freezing-point	231.928
Zinc freezing-point	419.527
Aluminum freezing-point	660.323
Silver freezing-point	961.78

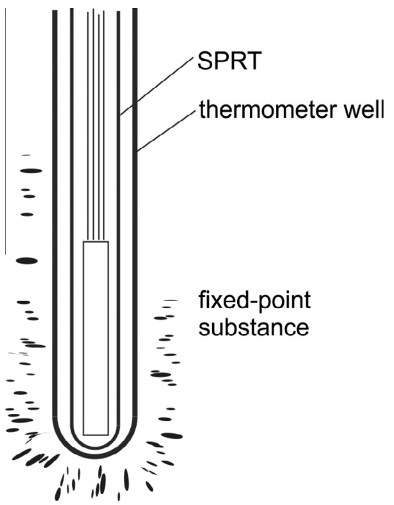

Fig. 1. SPRT during calibration.

It is important that the bushing material is chemically inert in order to avoid possible exothermic or endothermic reactions. The approximate thermal conductivities of relevant materials at room temperature are given in Table 2. These should be taken as an indication of relative differences between materials – the decisive conductivity value is the one at fixed-point temperature.

Bushings have a tubular shape and are inserted directly in the thermometer well. The use of bushings was already described in documents published by the International Bureau of Weights and Measures at the time ITS-90 was adopted. It was reported that the SPRT self-heating (*SH*) in water cells could be reduced by a factor of 5 with the use of close-fitting aluminum bushings [2]. The *SH* effect of SPRTs is a result of electrical resistance measurements.

Table 2
Approximate thermal conductivities k at 20 °C.

Material	k/W m^{-1} K^{-1}
Air	0.025
Helium	0.15
Ethanol	0.15
Water	0.58
Fused silica	1
Brass	120
Aluminum	230
Copper	400

In order to measure resistance, it is inevitable to pass an electrical current through the SPRT which additionally heats the sensor. The current is typically 1 mA for SPRTs with 25 Ω resistance at the water triple-point temperature. This *SH* can amount to several mK. A bushing lowers the thermal resistance between the cell and the SPRT and thus decreases the heating effect. The thermal resistance can be divided into internal and external thermal resistance: internal being from the sensor to the sheath and external from the sheath to the cell. A bushing influences only the external part of the thermal resistance.

Besides facilitating the thermal conduction and lowering the *SH*, bushings are also reported to increase the measurement repeatability. The use of fused silica bushings in water cells is recommended by Steur and Dematteis, especially if the well diameters are larger [3]. Also Smith et al. report an improvement in repeatability of measurements with triple-point of water cells and fused silica bushings for more than a factor of 2 [4].

There are also experimental and modeling results published on the effect of bushings on SPRT immersion profiles. The immersion profile shows the changes in measured temperature in different vertical positions of the thermometer in the well. In the ideal case without heat losses, the immersion profile tracks the hydrostatic pressure effect. In one of our previous articles we showed results which suggest that the immersion profiles of Inconel sheathed SPRTs in triple-point of water cells can be improved with the use of metal bushings with high thermal conductivities. On the other hand, for silica SPRTs such bushings did not improve the profiles [5]. Also Veltcheva et al. were able to improve the repeatability and scatter of immersion profile measurements in water cells by a factor of at least 2 with the use of long glass bushings [6]. Batagelj modeled the immersion profile measurements with an Inconel sheathed SPRT in an indium cell with different bushings and obtained the best result with the one made out of fused silica [7].

This paper is divided into two parts. The first part deals with thermometer self-heating. The *SH* of three different SPRTs was experimentally determined in the temperature range from the mercury to the zinc point with the use of different metal bushings: brass, aluminum and copper. Included are also the measured temperature differences that occur with the insertion of a bushing. Besides experimental results, some qualitative modeling results for higher temperatures are presented where bushings are practically not used. In the second part, a special emphasis was on the zinc point where immersion profiles were measured and modeled, again with the use of different bushings. Our goal was to research the effect of various bushing materials on self-heating and on immersion profiles of fused silica and Inconel sheathed SPRTs.

2. Thermometer self-heating

2.1. Experimental measurements

The *SH* of different SPRTs was determined with the basic two-current method [8]. The SPRT is placed in the cell