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Thermophysical data of liquid vanadium

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Abstract

Although vanadium is commonly used as an additive in the steel production, literature data for thermophysical properties of vanadium around the melting point are sparse and show, where available a variation over a wide range. This manifests especially in the melting temperature (variation of ±30 K), heat of fusion, or specific enthalpy.

This recent work presents the results of thermophysical measurements on vanadium including normal spectral emissivity at 684.5 nm. The aim was to obtain another full dataset of properties (enthalpy, heat of fusion, electrical resistivity, thermal conductivity, emissivity) of liquid vanadium to either confirm existing recommendations for certain properties or presenting newer measurements for comparison leading towards such recommendations.

Summarizing, the following results for thermophysical properties at the melting point have been obtained: radiance temperature at melting (650 nm) $T_{r,m} = 1993$ K, melting temperature $T_m = 2199$ K, normal spectral emissivity at melting (684.5 nm) $\varepsilon = 0.353$. An observed feature of all measured data and results is, that a much better agreement with literature references exists for the liquid phase than in the solid state, thus we have restricted the presentation to liquid vanadium.

Keywords: Heat of fusion; Melting temperature; Normal spectral emissivity; Pulse heating; Thermophysical properties; Vanadium

1. Introduction

Pure vanadium is a bright white metal with good corrosion resistance to, i.e., alkalis and salt water and is therefore commonly used as an additive in producing rust resistance in springs, and highspeed tool steels, since it is an important carbide stabilizer in making steels [1]. Despite its widespread use as a steel-additive, only few measurements on thermophysical properties of pure vanadium are reported in literature. A good example for this lack of precise data for vanadium is the melting point, which is only known and reported in a temperature range covering values from 2163 to 2223 K (see Table 1 for more details).

At the subsecond thermophysics laboratory in Graz thermophysical properties determinations are performed for many years and vanadium was one of the pure metals which have been investigated recently. The results of pure vanadium are presented within this paper which – by comparison to literature data – should either help to find some recommendations for thermophysical properties or act as an initial point for more or even more accurate measurements on vanadium.

Within this study, thermophysical properties of vanadium like specific enthalpy, electrical resistivity and isobaric heat capacity have been measured under containerless conditions by using a ohmic pulse-heating apparatus whereas the temperature determination combined with normal spectral emissivity measurements have been performed by pyrometry and the use of an ellipsometric approach with μs-resolution. This paper briefly describes the facilities used, presents all data with estimated uncertainties compared to available literature values, and discusses the results for vanadium in the liquid state.

2. Experiment setup and data reduction

2.1. Pulse-heating setup

The apparatus itself and the specific details on the data reduction used in these measurements have been extensively described elsewhere [10,11], wherefore a detailed description is omitted in this paper. In principle, a wire sample (typically 0.5 mm diameter and 40 mm in length) is clamped between two sets of brass jaws and resistively heated in an inert-gas-filled discharge chamber while the heating current, the sample

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Table 1
Values for the melting temperature T_m of pure vanadium from different sources [2–9]

Source of melting temperature	T_m (K)
Goodfellow Cambridge Limited (supplier) [2]	2163
Desai [3]	2202 (IPTS 68)
McClure and Cezairliyan [4]	2201 (ITS 90)
Aesar [5]	2183
Storms and McNeal [6]	2161
Oriani and Jones	2192
Hultgren et al. [8]	2199
Kocherzhinskii et al. [9]	2223

Note: The value given by McClure and Cezairliyan [4] is the value from [3] (2202 K) adapted to the ITS 90.

voltage drop, and the surface radiance are recorded. Since the volume of the inert gas is much lager than the volume of the sample it provides not only an isobaric environment but also helps preventing possible electrical discharges and/or contaminations.

The heating current, provided by a capacitor bank, is chosen to allow heating rates of about 10^8 K/s which result in an average experimental duration of about 30–60 μs per single measurement.

2.2. Temperature determination

Temperature measurements are performed with an optical pyrometer operating at 650 nm (FWHM 37 nm) to record the sample surface temperature as a function of experimental duration. Two possible techniques can be applied to obtain the thermodynamic temperature of the sample from its radiance temperature. Either an assumed melting temperature is assigned to the melting plateau in the radiance temperature records to determine the relative emissivity at this point whose value is assumed to stay constant throughout the liquid state or emissivity and its behaviour is directly measured (see section μs-DOAP) and temperature is calculated from Planck's radiation law and the actual measured emissivity. In this second case, the pyrometer has to be calibrated, e.g. against a tungsten striplamp (see Section 3.2.2).

Both mentioned methods lead to the same results in temperature, if emissivity is actually constant throughout the liquid phase but can lead to erroneously differing results in temperature for the first method if emissivity changes during the liquid state. As results have shown [12], a constant emissivity at 684.5 nm is the exception as almost all materials investigated so far show either an increase or a decrease in emissivity. To overcome this problem, only the latter method was used for determining the actual sample temperature within this work.

2.3. μs-Division-of-amplitude-photopolarimeter (μs-DOAP)

Normal spectral emissivity at a wavelength of 684.5 nm is directly measured by using a division-of-amplitude-photopolarimeter. The photopolarimeter uses an ellipsometric measurement approach but without any rotating devices with regard to the timescale used for pulse-heating experiments, based on the Stokes formalism for polarized light.

Basically, a polarized laser beam is focused on the surface of the sample wire and the change in polarization of the reflected beam is analyzed. As a result normal spectral emissivity at the given laser wavelength is obtained as a function of experimental direction which is used (as described in Section 2.2) to obtain the sample temperature. For more details on the μs-DOAP and the data reduction used see [13,14].

For easier understanding, a schematic display of the experimental setup including the DOAP can be seen in Fig. 1.

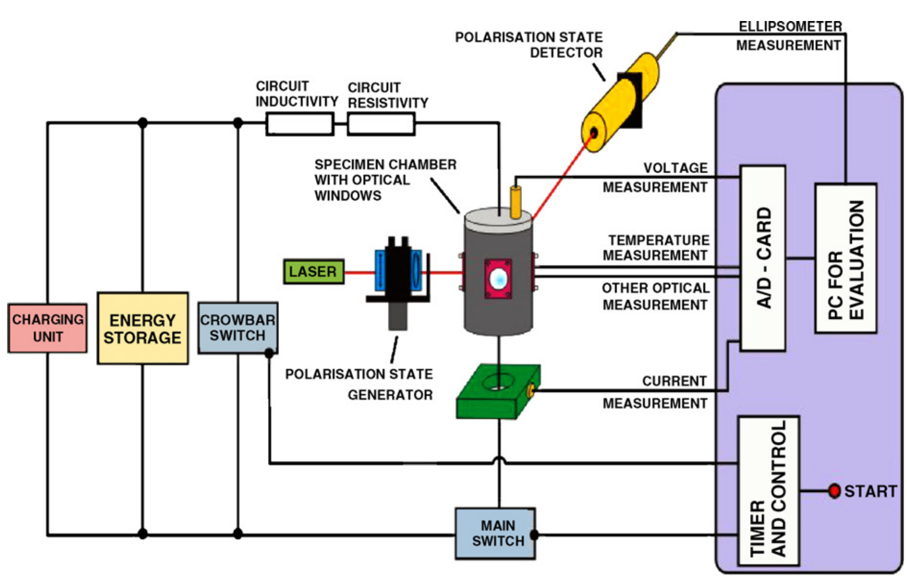

Fig. 1. Schematic overview of the experimental setup in Graz used to obtain thermophysical properties and emissivity of liquid vanadium.