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Spectral emissivity of transition metals of the X group in the melting point region

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An experimental study of the normal spectral emissivity of technical nickel, palladium and platinum in the solid polished and liquid phases near the melting points was carried out by the radiation method. The emission measurement was recorded by the bandwidth of the applied narrowband filters. The dependence of metal emission on the wavelength in the range of the radiation spectrum $0.26-10.6\,\mu$m is obtained. A comparative analysis with the literature data of other authors is carried out. A theoretical calculation of the emission is given according to the classical electromagnetic theory Hagen's formula and Rubens.

Keywords: normal spectral emissivity, melting range, nickel, palladium, platinum, wavelength.

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Introduction

Transition metals of group X such as nickel, palladium and platinum are widely used as catalysts in industrial thermal processes. Knowledge of thermophysical properties — emissivity in a wide wavelength band — allows to make thermotechnical calculations of radiant heat transfer in high-temperature processes [1], to predict the physical behavior of metals and to design new production lines and installations. The calculation of radiant heat transfer also allows you to intensify the performance and productivity.

1. Experimental part

The studies were carried out on an experimental setup in the wavelength range from 0.26 to $10.6\,\mu$m (Table 1), presented in the paper [2], by the radiation method.

The normal spectral emissivity ε_λ of metals in the melting point region of the solid polished and liquid phases was investigated. The measurements were carried out in an atmosphere of prepared argon after preliminary evacuation of the measuring cell. The argon atmosphere is necessary to eliminate the reactivity of the liquid metal mirror in order to increase the validity of the experiment.

As a resistive heater the authors chose a tantalum tape 2 mm thick with a recess in the center. The tape was preliminarily annealed until an oxide film Ta_2O_5 was formed to exclude the chemical reaction of the liquid metal with the heater. Subsequent cooling and extraction of the ingot by mechanical way showed good cohesive separation along the contact surfaces of the metal–resistive heater system.

Table 1. Spectral characteristics of the narrowband filters

Filter No.	1	2	3	4	5	6	7	8	9
Band-pass of filter, μm	0.26	0.42	0.69	0.99	1.63	1.97	4.2	7.3	10.6

Table 2. Characteristics of investigated samples of technical metals

Metal	Grade	Chemical purity,%	Tmelt., K
Nickel	H-1 Ay	99.95	1726
Palladium	PdA-1	99.95	1828.5
Platinum	PlA-1	99.95	2041.4

The procedure of the experiment is described in detail in the paper [3].

The estimate of the experiment error, carried out by the authors, is from 3 to 8%, depending on the temperature.

Samples of technical metals were used in the studies (Table 2).

2. Theoretical calculation method

This paper presents the result of theoretical calculation of the normal spectral emissivity ε_λ of the metals considered above according to the classical electromagnetic theory (Hagen and Rubens formula [4]):

$$\varepsilon_\lambda = 0.365(r/\lambda)^{1/2} - 0.0667(r/\lambda) + 0.0091(r/\lambda)^{3/2},$$

where r — resistivity of the metal at the test temperature, λ — wavelength.

In the theoretical calculation ε_λ for each metal, an array of experimental data on resistivity in the solid and liquid phases near the melting point [5,6] was used.

The results of the calculation performed are presented in the form of lines in Fig. 1–6.

The calculation of ε_λ for nickel and palladium gives good agreement in both the solid and liquid phases. The calculation of ε_λ for platinum in both liquid and solid phases turned out to be overestimated in relation to experiment. The possible inconsistency of the classical theory application to the intensity calculation for platinum in the considered range of the spectrum can be explained by the physical-chemical properties of the metal with the highest density in the group.

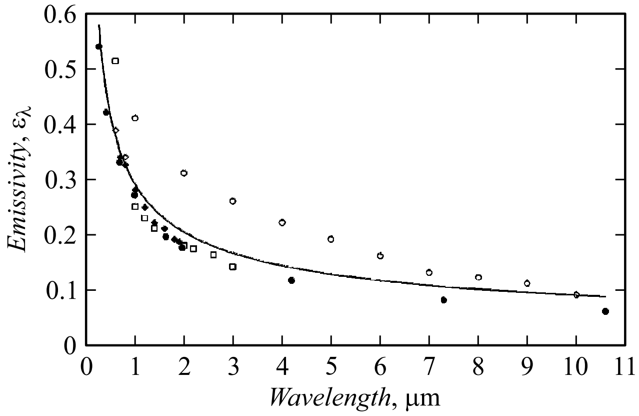

Figure 1. Nickel (solid phase).

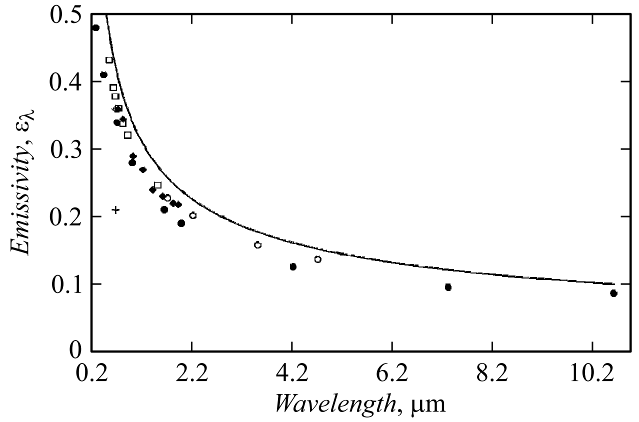

Figure 2. Nickel (liquid phase).

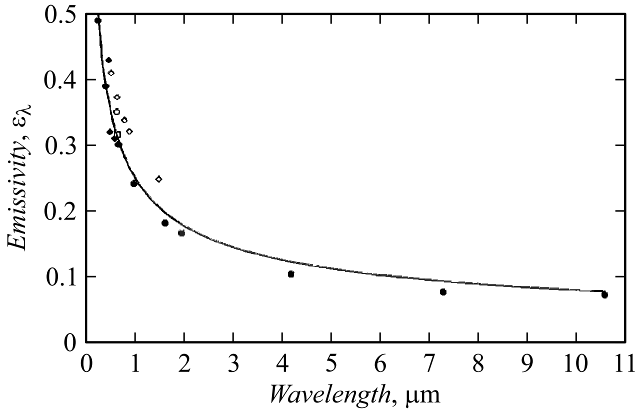

Figure 3. Palladium (solid phase).

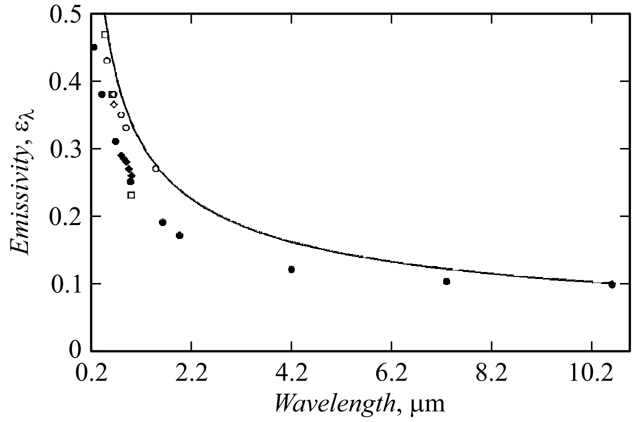

Figure 4. Palladium (liquid phase).

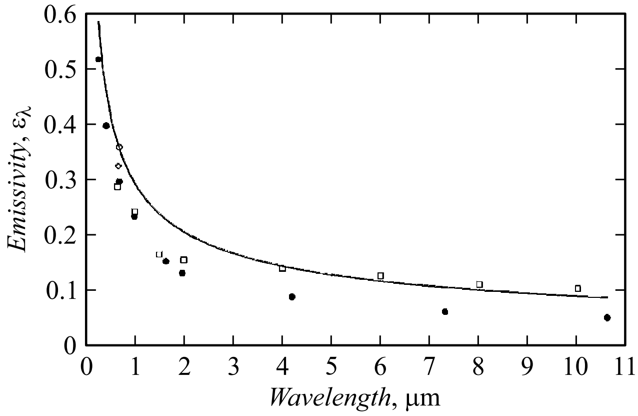

Figure 5. Platinum (solid phase).

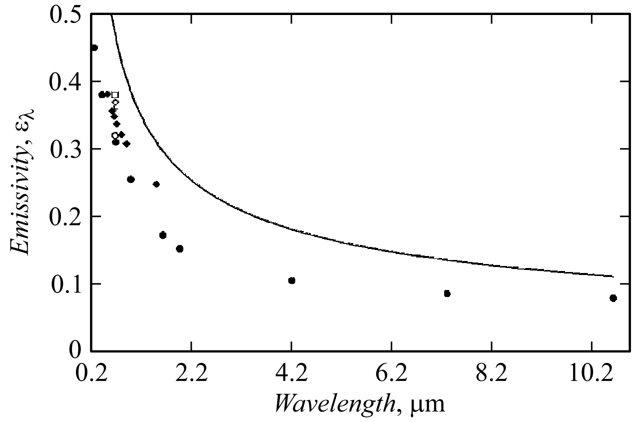

Figure 6. Platinum (liquid phase).

However, note that the most reliable thermophysical characteristics, in particular, the emissivity of structural materials, can only be obtained experimentally.

3. Experimental results and discussion

The results of the experiments, graphically presented in Fig. 1–6, are the average values of several independent measurements.

In the study of technical nickel the mirror-polished metal samples were used. The experiments were carried out at a temperature of 1715 K. The behavior of the normal spectral emissivity showed a classical distribution of the intensity drop along the wavelength (Fig. 1). The analysis of the published data showed good agreement in the spectral range from 0.4 to 2.5 μm [7–9]. Only value in [10] turned out to be overestimated in the entire studied spectral range, which can be explained by the experiment temperature (the difference was about 80 K).

The dependence of the emissivity of metals in the melting point region is very interesting from a scientific point of view, since the difference between the emissivity of the solid and liquid phases is directly related to the difference between the electronic.

The liquid phase of nickel was irradiated in the sample temperature range 1736 K (Fig. 2). Comparison of the radiation with the measurements of the authors [7,8,11–13] showed good agreement in terms of the intensity drop in the spectral region from 0.2 to 4.2 μm. The measurements of the this paper authors covered the range from 0.26 to 10.6 μm for all reference points of removable filters (Table 1).

The radiation in the melting region of the nickel liquid phase turned out to be by 10% higher than the radiation of the solid phase. The intensity drop is explained by the state properties of the crystal lattice of nickel as a transition metal.

Solid polished palladium was studied at temperature of 1812 K (Fig. 3). The spectral emissivity of palladium was compared with similar measurements by the authors of [8,13–15] in the spectral range from 0.26 to 1.5 μm. The comparison showed satisfactory agreement.

The liquid phase of palladium was studied at average experimental temperature of 1837 K. Comparison with studies [14–17] showed similar behavior of $\varepsilon\lambda$ in the confidence range of the error estimate starting from 0.26 μm up to 1.5 μm (Fig. 4). The studies were carried out, as in the previous cases, up to 10.6 μm.

The spectral distribution of the intensity of the normal emissivity of palladium was obtained, which is similar to the entire platinum group of the periodic system.

Metallic platinum was studied in polished solid state at average temperature of the experiment 2018 K. The platinum sample was the ingot. The intensity of the spectral radiation of solid platinum agrees well with the experimental data [8,12,18] in the region from 0.26 to 10.6 μm. The classical distribution of the intensity drop ε_λ as a function of the wavelength is illustrated in Fig. 5.

The liquid state of platinum was investigated in the temperature range 2053 K. Platinum point measurements of the intensity ε_λ according to [14,16,18–20] show an experimental comparison in the region of the spectrum from 0.26 to 1.5 μm. Measurement of ε_λ of platinum in this paper was carried out up to 10.6 μm. The intensity drop of the normal emissivity of platinum depending on the wavelength also agrees well with the similar behavior of the metals of this group in terms of the emission spectrum.

Conclusions

The example of the theoretical approach to the calculation of ε_λ of transition metals of the X group in the melting point region, presented in this paper, showed a satisfactory possibility of applying the classical electromagnetic theory in the visible and far infrared spectral bands.

The experimental measurement of the normal spectral emissivity of nickel, palladium and platinum in the melting point region was carried out.

The ε_λ study of the polished solid phase and of the liquid phase of metals in the melting point region showed a satisfactory agreement with similar studies by other authors, both qualitatively and quantitatively.

The behavior of the ε_λ of the studied metals corresponds to the characteristic descending dependence of the radiation on the wavelength in the melting point region.

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] R. Siegel, J.R. Howell. *Thermal Radiation Heat Transfer* (Taylor& Francis, NY., 2002)
[2] D.V. Kosenkov, V.V. Sagadeev. Tech. Phys., **92** (3), 272 (2022). DOI: 10.21883/0000000000
[3] D.V. Kosenkov, V.V. Sagadeev, V.A. Alyaev. Teplofizika i aeromekhanika, **28**, (6), 951 (2021) (in Russian).
[4] D.Ya. Svet. *Opticheskie metody izmereniya istinnykh temperatur* (Nauka, M., 1982)
[5] T.K. Chu, T.C. Chi. *Properties of Selected Ferrous Alloying Elements, III-1* (McGraw-Hill, Washington, 1981)
[6] J.W. Arblaster. Johnson Matthey Technology Review, **59**, 174 (2015).
[7] H. Watanabe, M. Susa, H. Fukuyama, K. Nagata. Intern. J. Thermophys., **24**, 473 (2003). DOI: 10.1023/A:1022924105951
[8] Y.S. Touloukian, D.P. DeWitt. *Thermal Radiative pPoperties: Metallic Elements and Alloys. Vol. 7, Thermophysical Properties of Matter*, ed. by Y.S. Touloukian, C.Y. Ho (IFI/Plenum, NY., 1970)
[9] E. Kaschnitz, J.L. McClure, A. Cezairliyan. Int. J. Thermophys., **19**, 1637 (1998). DOI: 10.1007/BF03344915

[10] G. Teodorescu. *Radiative Emissivity of Metals and Oxidized Metals at High Temperature* (Auburn University, 2007)
[11] K. Boboridis, A. Seifter, A. Obst, D. Basak. Intern. J. Thermophys., **28**, 683 (2007). DOI: 10.1007/s10765-007-0150-x
[12] C.P. Cagran, C. Brunner, A. Seifter, G. Pottlacher. High Temperatures-High Pressures, **34**, 669 (2002).
[13] E. Kaschnitz, J. McClure, A. Cezairliyan. Intern. J. Thermophys., **19**, 1637 (2014). DOI: 10.1007/BF03344915
[14] J.L. McClure, A. Cezairliyan, E. Kaschnitz. Intern. J. Thermophys., **20**, 1149 (1999).
[15] C. Cagran, G. Pottlacher. Platinum Metals Review, **50**, 144 (2006). DOI: 10.1595/147106706X129079
[16] S. Krishnan, G.P.R. Hansen, R.H. Hauge, J.L. Margrave. *Spectral Emissivities and Optical Constants of Electromagnetically Levitated Liquid Metals as Functions of Temperature and Wavelength.* JPL, Proceed. Second Noncontact Temperature Measurement Workshop (1990).
[17] M. Watanabe, M. Adachi, H. Fukuyama. J. Molecular Liquids, **324**, 115138 (2020). DOI: 10.1016/j.molliq.2020.115138
[18] B. Wilthan, C.P. Cagran, C. Brunner, G. Pottlacher. Thermochim. Acta, **415**, 47 (2004).
[19] F. Righini, A. Rosso, High Temp. High Press., **12**, 335 (1980).
[20] T. Baykara, R.H. Hauge, N. Norem, P. Lee, J.L. Margrave. High Temp. Sci., **32**, 113 (1991).