Emissivity of MOX fuel: a review

R. Calabrese

NUC-ENER-SIC (ENEA Bologna)

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Abstract Thermal radiation properties of nuclear fuel, especially at high temperatures, are relevant to safety analysis. For this purpose, the spectral emissivity of fuel should be determined well beyond the melting temperature. Emissivity is defined as the ratio of the emissive power of a body to the emissive power of a blackbody at the same temperature. The total hemispherical emissivity is relevant to determining the thermal radiation from a molten core. A review of experimental results published in the open literature has been performed. Recent results showed to be in agreement with recommendations provided by Bober and his co-authors.

Introduction Thermal radiation properties of nuclear fuel are relevant to safety analysis (Bober, 1980). The spectral emissivity $\epsilon(\lambda, T)$ of fuel should be determined at high temperature. The spectral radiance is expressed according to Eq. 1. In this equation L_b is the spectral radiance of a blackbody that depends on wavelength λ and temperature T.

$$L(\lambda, T) = \epsilon(\lambda, T)\, L_b(\lambda, T) \qquad (1)$$

Emissivity depends also on the angle of incidence so that a more general representation of emissivity is $\epsilon(\lambda, T, \theta)$. The total hemispherical emissivity is relevant to determining the thermal radiation from a molten core (Bober et al., 1980). The spectral emissivity is also necessary for reliable pyrometric measurements of fuel temperature, especially close to phase transition.

Measurements Bober and his co-authors measured the normal spectral emissivity (NSE) of UO_2 in the temperature interval 2000–4200 K at a wavelength of 630 nm and 10600 nm (Bober et al., 1980). The NSE of UO_2 showed a weak dependence on temperature up to the melting point. Thereafter, values of emissivity increase with increasing temperature (Bober et al., 1980). A limited effect of wavelength was noted for solid and liquid UO_2. For temperatures up to 2400 K, the results of Bober and co-authors are in fairly good agreement with data published previously (Cabannes et al., 1967), (Held and Wilder, 1969), and (Schoenes. 1978). Salikhov and co-authors aimed at studying the structural modification occurring in UO_2 approaching the pre-melting and melting temperatures by investigating the evolution of radiative properties (Salikhov et al., 1999). The authors conducted measurements in the interval 2000–4200 K at a wavelength of 644 nm. The spectral emissivity measured by the authors was in reasonable agreement with Bober's results. Values of emissivity were slightly increasing for temperatures below the melting point and practically constant above. Similar indications come from measurements performed by other authors such as (Ronchi and Sheindlin, 2002), (Manara et al., 2005; 2008), (Pavlov, 2017). Measurements performed on PuO_2 and MOX fuel confirmed the data by Bober and the fact that the emissivity of MOX is not significantly different from that of UO_2. Part of experimental measurements are presented in Fig. 1. In Fig. 2 we present the measurement of emissivity in the far infrared region that was performed by Bober and his co-authors. Contrary to the response in the visible region mentioned above, in the far infrared region the emissivity of liquid UO_2 decreases with temperature.

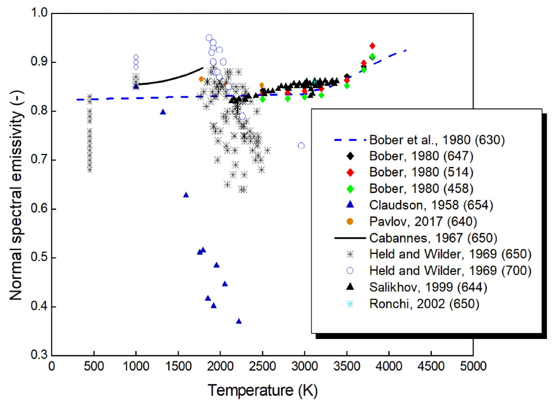

Figure 1: NSE of UO_2 as a function of λ and T

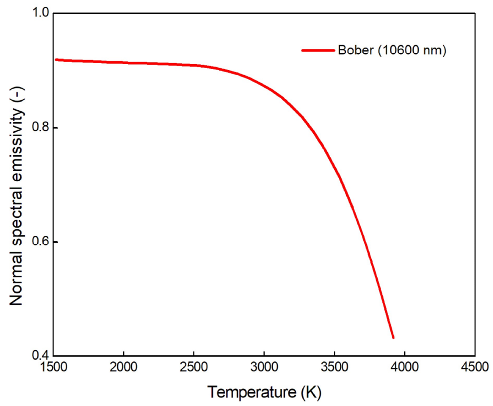

Figure 2: NSE of UO_2 as a function of T (infrared region)

Conclusion Recent results confirm the validity of the correlations developed by Bober and Fink for the evaluation of NSE as a function of temperature in the visible range. As concerns the total hemispherical emissivity of solid oxide fuel, consensus was noted on the relationship recommended by Fink and developed by Gentry. A different conclusion can be drawn regarding the total hemispherical emissivity of the liquid phase. In this case, measurements are needed in the near and far infrared to confirm the results of Bober that indicate a decrease of emissivity with temperature.

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Contact | R. Calabrese
NUC-ENER-SIC

Mail | rolando.calabrese@enea.it