DATA PROCESSING OF SPECTRAL RADIATION FOR TEMPERATURE MEASUREMENT

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ABSTRACT
This study describes the temperature determination method with
sufficient accuracy even in the case that the emissivity of sur-
face is significantly dependent on the wavelength.

INTRODUCTION
The two color pyrometry is on the basis of the assumption that
the emissivity ratio of two near wavelengths is near or equal to
unity.   However,this assumption is not well satisfied in some
practical conditions[1)].

Thus, especially desirable is the radiation pyrometry such as
enables temperature measurement with more moderate restriction on
the emissivity factor but with. sufficient accuracy.   Spectrometry
and a certain data processing of the thermal radiation look pro-
mising for this problem.

DATA PROCESSING METHOD
The measurement system necessary for the present technic is the
same as the traditional radiation pyrometry, except needing a
spectrometer.

Applying the Wien formula approximate to the Planck law to the
radiation from substance with normal spectral emissivity $\varepsilon(\lambda)$

$$\varepsilon(\lambda)=FD(\lambda)\exp(c_2/T\lambda) \tag{1}$$
$$D(\lambda)=E(\lambda)/E_{Tb}(\lambda)\exp(c_2/Tb\lambda) \tag{2}$$

where $F=f(s,\omega)/f_b(s_b,\omega_b)$, is wavelength,T surface temperature of
the substance,$E(\lambda)$ and $E_{Tb}(\lambda)$ outputs on the spectrometry for the
substance and the black body,respectively, c_2 the universal con-
stant$(1.4388Kcm)$, $f(s,\omega)$ factor concerning the viewing conditions,
and suffix b stands for the black body. $f(s,\omega)$ depends both on the
projected area of the substance involved in the focused domain s

and on the solid angle ω which a light collector subtends around the center of the domain.

Consider the following working function y which is defined in the wavelength range measured in the spectrometry:

$$y=D(\lambda)\exp(c_2/Ts\lambda) \tag{3}$$

Ts is the scanning temperature which takes consecutive discrete values with an interval ΔTs in the sufficiently wide temperature range.

The procedure for the temperature determination is as follows.
(1) At each value of Ts,the following polinomial

$$y_f =a_0+a_i\lambda +...+a_m\lambda^m \quad (m=1,2,...) \tag{4}$$

is fitted to y in Eq.(3) by means of the least square method.
(2) The sum of squares of residuals S(Ts,m) is calculated by

$$S(Ts,m)=\sum(1-y_f/y)^2 \tag{5}$$

and a S-map is drawn by plotting S(Ts,m) against Ts with m as parameter.
(3) Minimum points are searched on the S-map. The Ts value which gives a minimum point,Td,could be equal or nearest to the true temparature Tt.

The validity of the procedure is illustrated in the following way. $D(\lambda)$ has always the following form

$$D(\lambda)=\mathcal{E}(\lambda)\exp(-c_2/Tt\lambda)/F \tag{6}$$

although $\mathcal{E}(\lambda)$,F and Tt are unknown.

Substitution of Eq.(6) into (3) yields

$$y=\mathcal{E}(\lambda)\exp(c_2(1/Ts-1/Tt)/\lambda)/F \tag{7}$$

$\mathcal{E}(\lambda)$ can be approximated by a polinomial with order n.

It is understood from Eq.(7) that the curve fitting treatment for y in progress of the temperature scanning in Eq.(3) is,in fact, equivalent to the searching of the minimum deviation of the scanning temperatures from the true. Eq.(7) shows that, for $\mathcal{E}(\lambda)$ being linear,a situation Ts=Tt brings about a distinct minimum of S with m=1 and vice versa, because the exponential factor is always curvilinear except Ts=Tt. However, for n>1, this theorem is not always true.

SIMULATION OF THE TEMPERATURE DETERMINATION

The above is further illustrated by the simulation of the temperature determination for the various behavior of $\mathcal{E}(\lambda)$. Fig.1 shows some of the emissivity plots used for the simulation. The

$\mathcal{E}(\lambda)$-curves considered are divided into three categories: linear
lines, monotonic curves and curves with either one maximum or one
minimum.

The radiation data $D(\lambda)$ to be applied to the simulation were
generated by using Eq.(6) with the assumed emissivity and tempe-
rature Tt(=900 and 1300K). And then the $D(\lambda)$-data were processed
according to the procedure. Since F is independent of λ, any
variation in F can not affect the temperature determination at
all,so F=1 was assumed.This is also the case for the two color
pyrometry.

 1. Case of $\mathcal{E}(\lambda)$ with definite order

Fig.2 shows the S-map for the asterisked curve with n=3 shown
in Fig.1. The minimum point for S(Ts,m=3) locates far below that
for S(Ts,m=2): this situation reveals that the order of the $\mathcal{E}(\lambda)$-
curve n equals 3, coinciding with the given value of n. For S(Ts,
m=4), the minimum point deviates usually not so far from Tt.

The simulation for the $\mathcal{E}(\lambda)$-curves with definite orders have
proved that it is possible to determine temperature with suffi-
cient accuracy if $\mathcal{E}(\lambda)$ is of order equal to or less than 3.

 2. Case of $\mathcal{E}(\lambda)$ without definite order

The processing of the partial data of $D(\lambda)$ is rather more
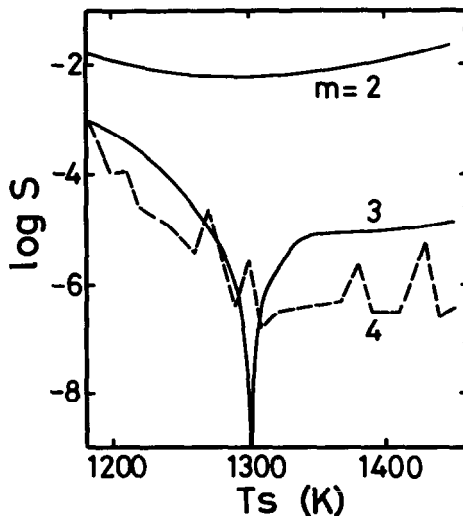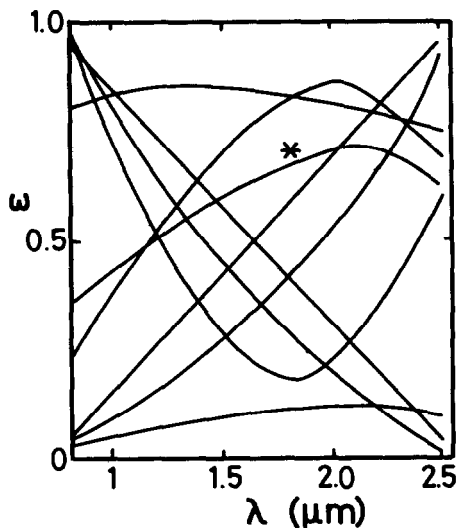favorable than the total data processing at once,because a partial

Fig.1 Examples of $\mathcal{E}(\lambda)$-curves.   Fig.2 The S-map. n=3, Tt=1300K.

segment of a $\varepsilon(\lambda)$-curve is often simpler than the total. The $D(\lambda)$-data obtained by use of the curves with indefinite order shown in Fig.1, were treated according to such a partial data processing as well as the total data processing for comparison. The standard deviations for the differences between Td and Tt are summerized in Table 1.

APPLICATION

The present technic was practically applied to the normal spectral radiation which emitted from the surface of the powder samples as well as the clean platinum plane plates. One pair of thermocouple was inserted in the sample holder as a reference. The ranges of the reference temperature (Tt) and wavelength on the spectrometry were from 850 to 1250K and from 0.9 to 2.3 μm, respectively. The standard deviations for the differences between Td and Tt are summerized in Table 2.

It is also possible to obtain Td by the two color method.The standard deviations are also summerized in the both tables.

Table 1   Standard deviations $\sigma(K)$ for the simulations(Tt=900 and 1300K).

processsg. mode $\quad\varepsilon$	linear lines(8)	curvilinear lines	
		monotonic(11)	with max. or min.(9)
total, m=4	2.5(m=1)	38	30
partial,m<4		17	17
two color	615	2444	47

The figures in the parentheses are of lines.

Table 2   Standard deviations $\sigma(K)$ for the applications.

processsg. mode $\quad$ sample	powders (34)	platinum plates(4)
total, m=1	10	19
two color	9	54

The figures in the parentheses are of cases.

REFERENCE

1 Z. Morita, K. Fujita, M. Kitaura, T. Otsuka, and A. Adachi, TETSU-TO-HAGANÉ 57 (1971) 986