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A Review of Automatic Radiometric Pyrometry

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A Review of Automatic Radiometric Pyrometry

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The long-term accuracies of automatic radiometric pyrometers have been analyzed for the temperature range 1000°K to 3000°K and standards of good performance are estimated to be 0.4%, 0.7%, and 1.1% of the actual target temperature for automatic brightness, radiation, and two-color pyrometers respectively. Similar high standards for short-term accuracies, i.e., assuming negligible drift errors over the operating period, are estimated to be 1/4%, 1/3%, and 1/2% respectively. Long-term errors due to instability alone are estimated to be 0.3%, 0.6%, and 1.0% respectively. Scale errors and errors due to emittance uncertainties and environmental factors are not included. Accuracy below 1100°K will be somewhat poorer than this unless a blackbody source and thermocouples are used for calibration.

A means is described to at least roughly predict which type of pyrometer will probably have the least error due to uncertainties in the emittance of the object surface. For different materials and classes of materials there are marginal or decisive advantages to using a brightness or two-color pyrometer insofar as errors due to emittance are concerned; the total radiation technique is invariably subject to greater errors of this kind.

The effect of environmental factors on the accuracy of radiometric temperature measurements is discussed briefly. The two-color pyrometer may be less sensitive in some cases to the influences of atmospheric contaminants or other obstructions in the radiation transmission path. Its superiority in this respect cannot generally be assumed, however, because of possible reflection of ambient radiation by dust or smoke particles, changes in the radiation spectrum due to dispersion, absorption, or the formation of films, and because of possible disturbances due to the dynamic nature of the transmission media. A two-color pyrometer, operating in the visible spectrum, is apt to be more affected by ambient light than the other types, largely because such radiation ordinarily has a very different color temperature than the target, but only relatively small amounts of ambient light energy are actually reflected for the target surface. There will usually not be significant errors due to ambient illumination at temperatures above about 1000°C.

INTRODUCTION

Optical and radiation pyrometers have been used extensively over the past several decades. As a result there is a great deal in the literature pertaining to their theory, design, and application.[1] The more recent pyrometers suitable for continuous measurement and control[2] have stimulated interst in the relative capabilities and limitations of the different types of pyrometers now available. The prime purpose of this paper is to review the more fundamental characteristics of the three major types of automatic radiometric pyrometers, toward the end of helping to predict their relative usefulness for different applications. It is anticipated that this material can aid, but will not necessarily be conclusive in the optimum choice of pyrometer because of the great number of technical as well as economic factors involved, the lack of adequate spectral emissivity data for many * materials, and particularly because of the anomalous behaviour of target surfaces and transmission media that is frequently encountered in practice.

Emphasis is on the temperature range from 1000° to 3000°K. The areas of major interest are (1) stability, (2) errors due to emittance uncertainty, (3) accuracy, and (4) environmental factors.

STABILITY

The steady state output functions of the three commercially available types of radiometric pyrometers may be expressed to a good approximation as follows :

Brightness Pyrometer

$$\blacktriangleright\ g_b(T)=\frac{K_{1b}}{K_{2b}}K_{3b}\,\epsilon_e\,e^{-C_2/\lambda_e(1/T-1/T_{rb})} \qquad (1)$$

T is the absolute temperature of the target, and T_{rb} is that of a reference source in the instrument. λ_e is "effective wavelength"; for the purposes of this paper, effective wavelength is adequately defined as the peak wavelength of the narrow spectral passband to which the instrument responds. K_{1b} , K_{2b} are instrument parameters relating to optical transmittance of the target energy and the reference energy paths, respectively. K_{3b} is the gain of the instrument's amplifier or the steady state transfer function of its servomechanism. C_2 is a constant of Wien's spectral radiation law, and ϵ_e is the target emittance at λ_e and T.

Total Radiation Pyrometer

$$\blacktriangleright\ g_t(T)=\frac{K_{1b}}{K_{2b}}K_{3t}\,\epsilon_t\,\sigma\frac{T^4}{T_{rt}^4} \qquad (2)$$

K_{1t} , K_{2t} , K_{3t} , and T_{rt} correspond to the parameters of the brightness pyrometer defined previously. ϵ_t is the total emittance of the target, and σ is the Stefan-Boltzmann radiation constant.

Two-Color Pyrometer

$$\blacktriangleright\ g_r(T)=(K_{1r}K_{2r}K_{3r}\lambda_r^{-5})\,\epsilon_r\,e^{-n/T} \qquad (3)$$

$n=C_2(1/\lambda_1-1/\lambda_2)$, λ_1 and λ_2 being the long and short effective wavelengths of the pyrometer, respectively. K_{1r} is the ratio of photodetector spectral sensitivities at λ_1 and λ_2 . K_{2r} is the ratio of optical transmission through the instrument at λ_1 and λ_2 . $\lambda_r=\lambda_1/\lambda_2$, and ϵ_r is the ratio of target emittances at λ_1 and λ_2 .

The stability of these instruments will depend largely on the stability of their parameters. The change in their indicated temperature as a function of small parameter changes may be obtained by differentiating Eqs. (1) to (3).

$$dT = \frac{\lambda_e}{C_2} T^2 \left(\frac{dK_{1b}}{K_{1b}} - \frac{dK_{2b}}{K_{2b}} + \frac{dK_{3b}}{K_{3b}} \right) + \frac{T^2}{T_{rb}} \frac{dT_{rb}}{T_{rb}} + T \left(1 - \frac{5T\lambda_e}{C_2} \right) \frac{d\lambda_e}{\lambda_e} \quad \text{deg C} \tag{4}$$

$$dT = 0.25\, T \left(\frac{dK_{1t}}{K_{1t}} - \frac{dK_{2t}}{K_{2t}} + \frac{dK_{3t}}{K_{3t}} \right) - T \frac{dT_{rt}}{T_{rt}} \quad \text{deg C} \tag{5}$$

$$dT = \frac{T^2}{n} \left(\frac{dK_{1r}}{K_{1r}} + \frac{dK_{2r}}{K_{2r}} + \frac{dK_{3r}}{K_{3r}} \right) + T \left[\frac{1}{1 - \lambda_1/\lambda_2} + \frac{1}{n} T \left(\frac{2.3 B_1}{\lambda_1} - 5 \right) \right] \frac{d\lambda_1}{\lambda_1} + T \left[\frac{1}{1 - \lambda_2/\lambda_1} + \frac{1}{n} T \left(5 - \frac{2.3 B_2}{\lambda_2} \right) \right] \frac{d\lambda_2}{\lambda_2} \quad \text{deg C} \tag{6}$$

The λ_e error term in Eq. (4) assumes that K_{2b} has a spectral characteristic proportional to $\lambda^5 e^{C_2/\lambda T_{rb}}$ in the vicinity of the nominal effective wavelength and that $d\lambda_e$ is due to drift in the filter peak wavelength with time and environmental temperature. Scale errors due to a shift of λ_e as a function of target temperature will have the same form under these conditions and roughly the same magnitude; these may be considered negligible by comparison since they can be largely eliminated during calibration. Errors due to effective wavelength uncertainty when measuring nonblackbody sources will be discussed in the section on Accuracy. In Eq. (6), B is the slope of log $R(\lambda)$, where $R(\lambda)$ is the spectral response of the detector and has the following form in the vicinity of λ_1 and λ_2 :

$$\log R(\lambda) = A + B/\lambda \tag{7}$$

B_1 and B_2 can be changed, in effect, by the spectral characteristics of K_{1r} and K_{2r} . A good design compromise of this nature should result in a maximum probable error due to filter drifts of less than about 8°C. in Eq. (5) it has been assumed that errors due to small spectral response uncertainties will be neglibible in a very broad bandwidth radiation pyrometer.

Estimates of probable long term parameter uncertainties involve a combination of experience, experimental data, and engineering judgment. The drift terms should be summed on a statistical basis in accordance with their randomness and independence. Reasonable standards for long term parameter stability are summarized in Table I. It is assumed that the instruments are designed, constructed, and applied in accordance with the best engineering practices known at this time. Some specific requirements are:

1. Effective measures have been taken to minimize the influence of detector sensitivity, e.g., by the use of very stable reference sources and scanning techniques, unless the detector is inherently stable in the order of 0.5%.

2. Great care is exercised to protect the optics of the instrument from environmental and internal sources of contamination.

3. The most stable optical components and materials available are used. Narrow band and spectral compensating filters are used in the manner required to minimize spectral and other drift errors.

4. Electronics and electromechanical elements are highly stabilized.

Figure 1 is a plot of the estimated probable long term instability of automatic radiometric pyrometers based on the data in Table I and assuming the following nominal parameters: $\lambda_e = 650\,m\mu$; $\lambda_1 = 650\,m\mu$; $\lambda_2 = 510\,m\mu$; $n = -6000$; $T_r = 1300^\circ K$ The various instability errors are summarized in Table II, showing the relative contributions of each source of error. Certain design approaches, other than those assumed here, would result in different errors due to effective wavelength uncertainty, but such differences will not seriously affect the end results.

Summarizing the stability characteristics of radiometric pyrometers:

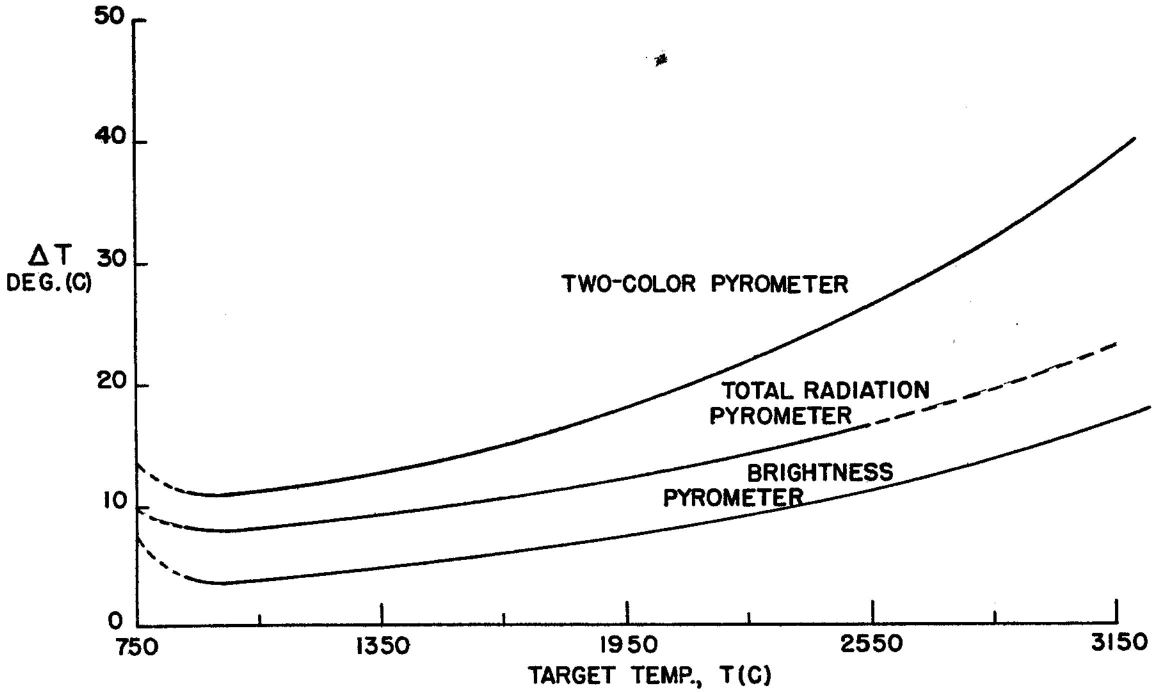
► It is evident that a realistic stability specification for any wide range radiometric pyrometer should be expressed as a function of the object temperature.

► The long term instability errors of high performance brightness, total radiation, and two-color pyrometers in the temperature range of 1000°K to 3000°K are estimated to be 0.3%, 0.6%, and 1.0% of the actual target temperature, respectively. Above 3000°C, stability becomes somewhat poorer than this.

ERRORS DUE TO EMITTANCE UNCERTAINTY

Equations (1) to (3) show that some value of target emittance must be assumed in the calibration and use of radiometric pyrometers. It is the general practice to reference the calibration of these instruments to a blackbody radiator, so that

$$\epsilon_e = \epsilon_t = \epsilon_r = 1 \tag{8}$$



ESTIMATED LONG TERM ACCURACY

FIG. 5

Table I. Estimated parameter drift.

Parameter Drift Term	Brightness Pyrometer	Total Radiation Pyrometer	Two-Color Pyrometer
$\sum_{rms} \frac{dK_1}{K_1} + \frac{dK_2}{K_2} + \frac{dK_3}{K_3}$	1.5%	1.5%	1.5%
$\frac{dT_r}{T_r}$	0.1% (approx 1°C)	0.1% (approx 1°C)	
$\frac{d\lambda}{\lambda}$	0.2% (approx 1 $m\mu$)	-	0.2%/0.2% (approx 1 $m\mu$)

Errors in deriving the true temperature from a radiometric measurement of a nonblackbody result from uncertainties in the pertinent target emittance and the spectral parameters which are involved in the transformation. Uncertainties in target emittance are due largely to its dependence on what are frequently anomalous or unpredictable factors such as the chemical and physical condition of the target surface; thus, there are uncertainties involved in the published emissivity data as well as for each specific target surface. The sensitivity of the different pyrometer types to small errors in the target emittance is readily derived by differentiating Eqs. (1) to (3).

$$dT = T^2 \frac{\lambda_e}{C_2} \frac{d\epsilon_e}{\epsilon_e} \tag{9}$$

$$dT = 0.25\,T \frac{d\epsilon_t}{\epsilon_t} \tag{10}$$

$$dT = \frac{T^2}{n} \frac{d\epsilon_r}{\epsilon_r} = \frac{T^2}{n} \left(\frac{d\epsilon_1}{\epsilon_1} - \frac{d\epsilon_2}{\epsilon_2} \right) \tag{11}$$

dT is the error in deg C resulting from an error, $d\epsilon$, in the assumed emittance of the target surface.

The magnitude of dT cannot be determined from Eqs. (9) to (11) unless there is some basis for estimating the target emittance error. It is reasonable to assume that generally the temperature measurement error due to emittance uncertainty will be in proportion to the difference between true and apparent temperature due to the nominal surface emittance. On this basis it is possible to predict the probable relative magnitude of this error between the different types of pyrometers, with a minimum amount of emissivity or emittance data for a particular material. Integrating Eqs. (9) to (11) and taking the appropriate ratios:

$$\frac{\Delta T_r}{\Delta T_b} = \frac{C_2}{n\lambda_e} \frac{\ln \epsilon_r}{\ln \epsilon_e} \tag{12}$$

$$\frac{\Delta T_b}{\Delta T_t} = \frac{1 - \dfrac{1}{1 - T\lambda_e / C_2 \ln \epsilon_e}}{1 - \epsilon_t^{1/4}} \tag{13}$$

ΔT_b, ΔT_t, and ΔT_r are the differences between true and apparent temperatures as measured with the brightness, radiation, and two-color pyrometers, respectively. $\Delta T_t / \Delta T_r$ may be derived from the other two ratios.

Equation (12) is plotted in Fig. 2. Because Eq. (13) has four variables it is more convenient to plot ΔT_b and ΔT_r separately, as in Fig. 3, and to compute $\Delta T_b / \Delta T_t$ from these data. Using such graphs and knowing the nominal values of ϵ_e, ϵ_t, and ϵ_r for a given material and temperature range, it is possible to make at least a rough prediction of relative emittance errors.

The ratios for a few common materials are located in Figs. 2 and 4. It is shown that for a number of high temperature metals such as Ta, Mo, Ti, and W the use of a two-color pyrometer should result in the smallest emittance errors. An experimental program was carried out at the Scovill Manufacturing Company to compare the performance of different radiometric pyrometers in measuring the temperature of induction heated brass alloys. The data taken are summarized in Table III.[5] A visually operated brightness pyrometer was used initially; later work with an automatic brightness pyrometer gave essentially the same results. These results showed the brightness pyrometer to be the best for this application, for several important reasons,[6] one of these being that errors due to the emittance of such materials will generally be substantially smaller than with the other types. In many cases it will be apparent that the probable difference in errors due to emittance will be small, and other considerations will be relatively more important.

It is clear from these data that the broad band radiation pyrometer is apt to have a significantly larger error of this kind for most materials than the other types, particularly at the lower temperatures. The development of new infrared detectors has made a relatively narrow band radiation pyrometer possible. This type of instrument will function much like a brightness pyrometer does in the visible spectrum and will generally have less error due to emittance uncertainty than the total radiation pyrometer.

It is interesting to determine the limit of Eqs. (12) and (13) as ϵ_r, ϵ_e, and $\epsilon_t \longrightarrow 1$.

$$\Delta T_r / \Delta T_b \longrightarrow n\lambda_e / C_2 \qquad (\text{as } \epsilon_r \,\&\, \epsilon_e \longrightarrow 1)$$

$$\Delta T_b / \Delta T_t \longrightarrow 4(\lambda_e / C_2) T \qquad (\text{as } \epsilon_e \,\&\, \epsilon_t \longrightarrow 1)$$

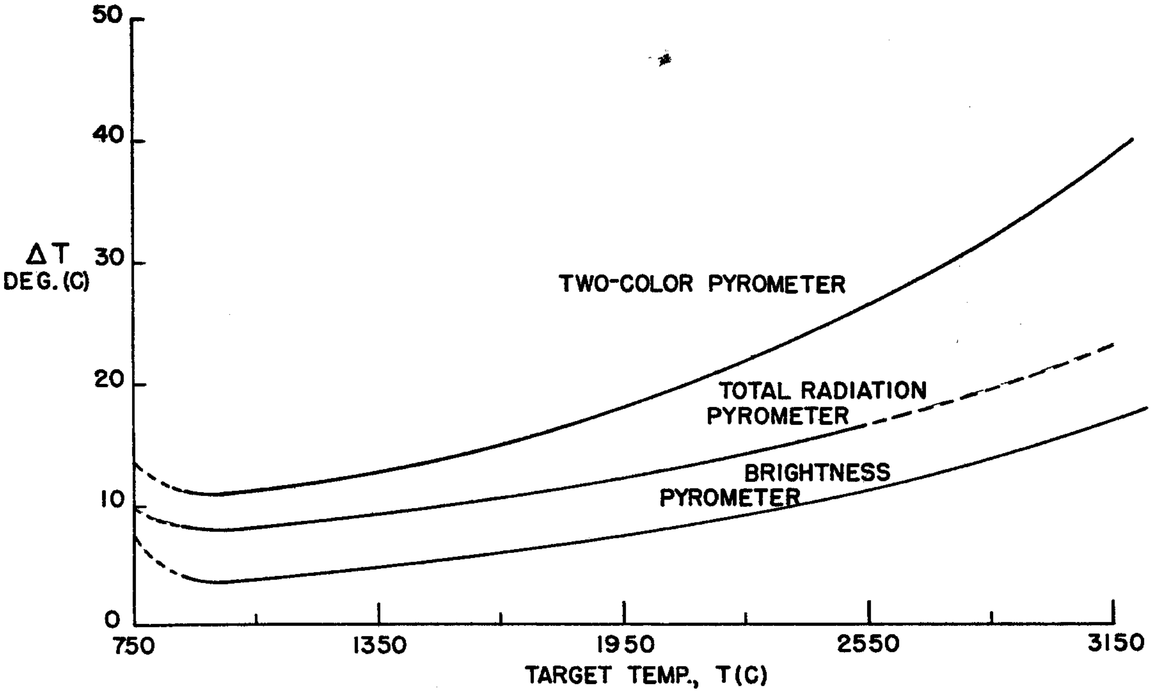
$$\Delta T_r / \Delta T_t \longrightarrow 4T/n \qquad (\text{as } \epsilon_r \,\&\, \epsilon_t \longrightarrow 1)$$

These relationships show that the brightness pyrometer will probably have less than one-quarter the error of a radiation pyrometer and about one-third the error of a two-color pyrometer due to any uncertainty in the emittance of a near blackbody radiator such as may be used for calibrating these instruments.

There is another source of emittance error because the relationship between apparent and true temperature is a function of effective wavelengths or bandwidth. The error due to small effective wavelength deviations in brightness and two-color pyrometers may be determined by first integrating Eqs. (9) and (11) over the limits of true and apparent temperatures, blackbody and actual emittance, and then differentiating the resultant equations with respect to effective wavelength.

$$dT_b = T_b^2 \frac{\ln \epsilon_e}{C_2} d\lambda_e \tag{14}$$

$$dT_r = T_r^2 \left[-\frac{E}{C_2} \left(\frac{\lambda_2}{\epsilon_2} d\lambda_1 + \frac{D\lambda_1}{\epsilon_2^2} d\lambda_2 \right) \right] \tag{15}$$



ESTIMATED LONG TERM ACCURACY

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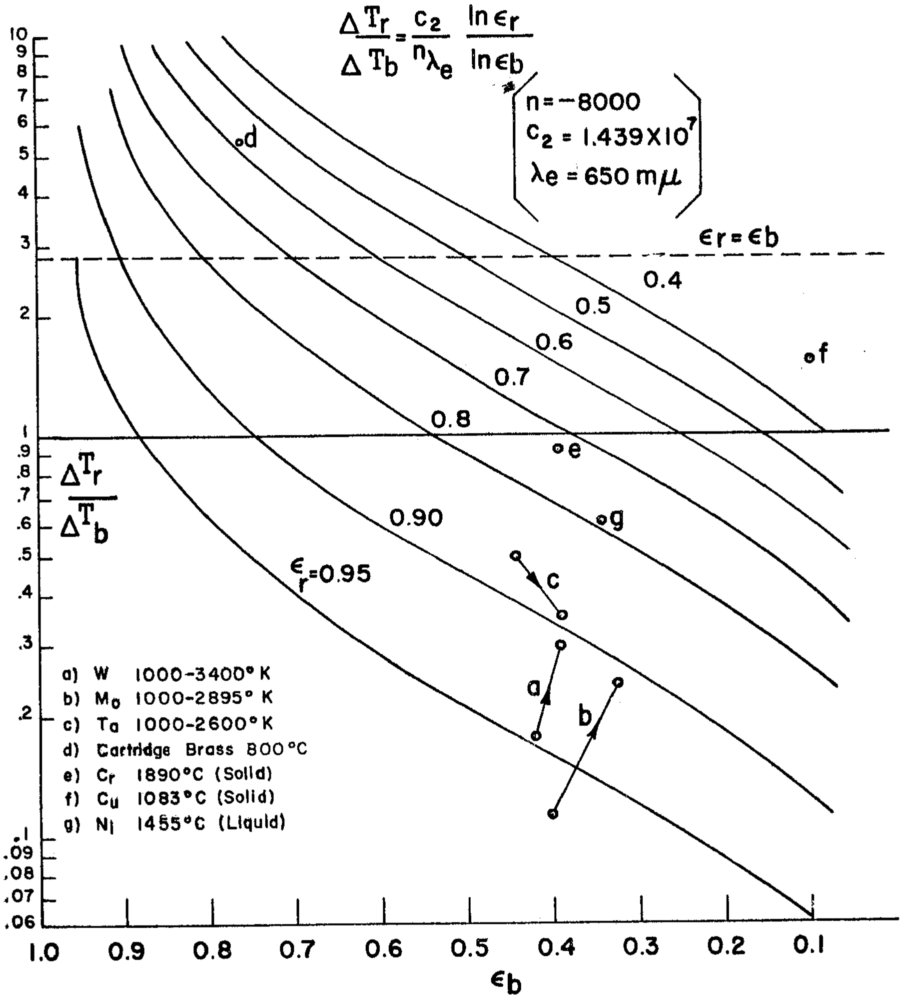


ΔT_r = ACTUAL TEMPERATURE–"COLOR" TEMPERATURE (°K)

ΔT_b = ACTUAL TEMPERATURE–"BRIGHTNESS" TEMPERATURE (°K)

$\frac{\Delta T_r}{\Delta T_b}$ VS ϵ_e AND ϵ_r

FIG.2

T_b and T_r are the actual brightness and ratio temperatures of the target. In Eq. (15) it is assumed that the spectral emittance can be expressed, with reasonable accuracy, as follows:

$$\epsilon(\lambda) = D - E\lambda \qquad (16)$$

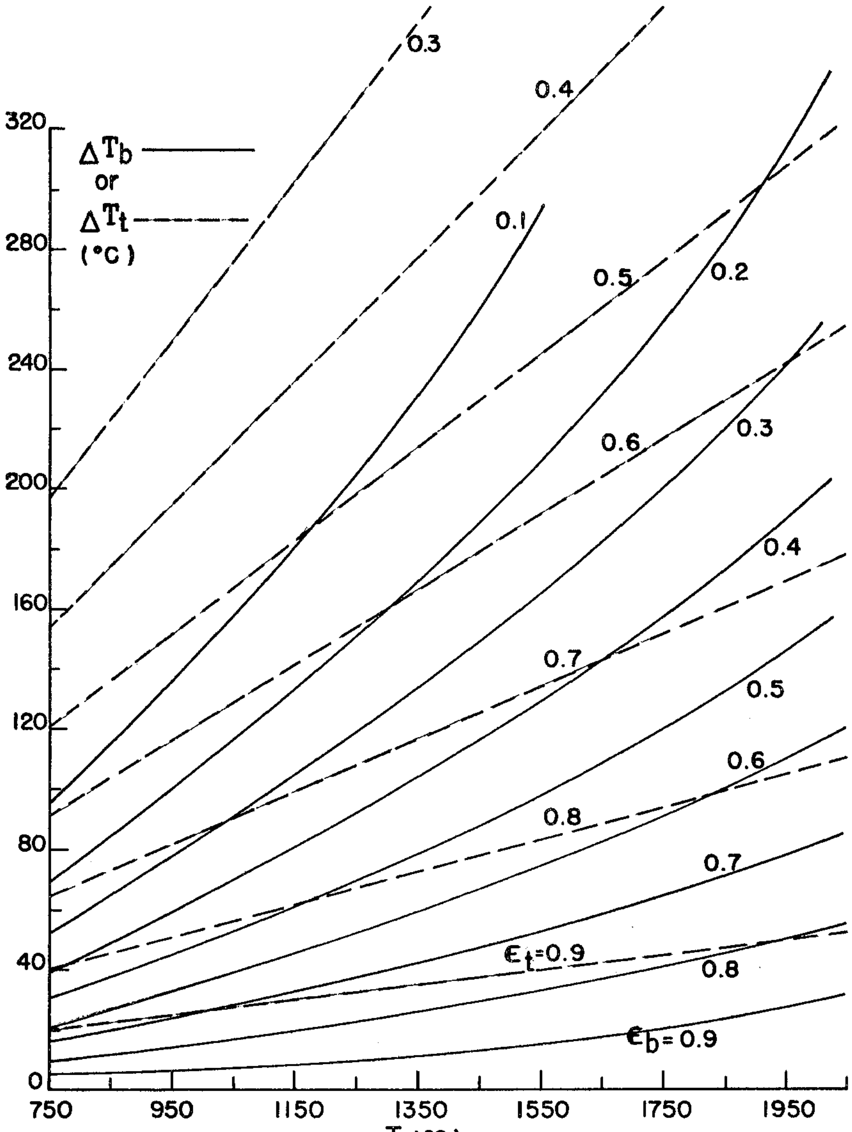
Taking the ratios of Eqs. (9) to (14) and (11) to (15), one finds that errors due to emittance uncertainty will be much greater than those due to effective wavelength uncertainty for any set of conditions likely to occur in practice.

ACCURACY

The most important errors in these instruments should be due to instability, and the limitations of the calibration techniques. There are many other sources of error, such as scale extrapolation and meter nonlinearity, but in a well designed instrument these should have relatively little effect on over-all accuracy; significant errors of this repeatable type may be reduced by the use of calibration correction curves or hand-drawn scales.

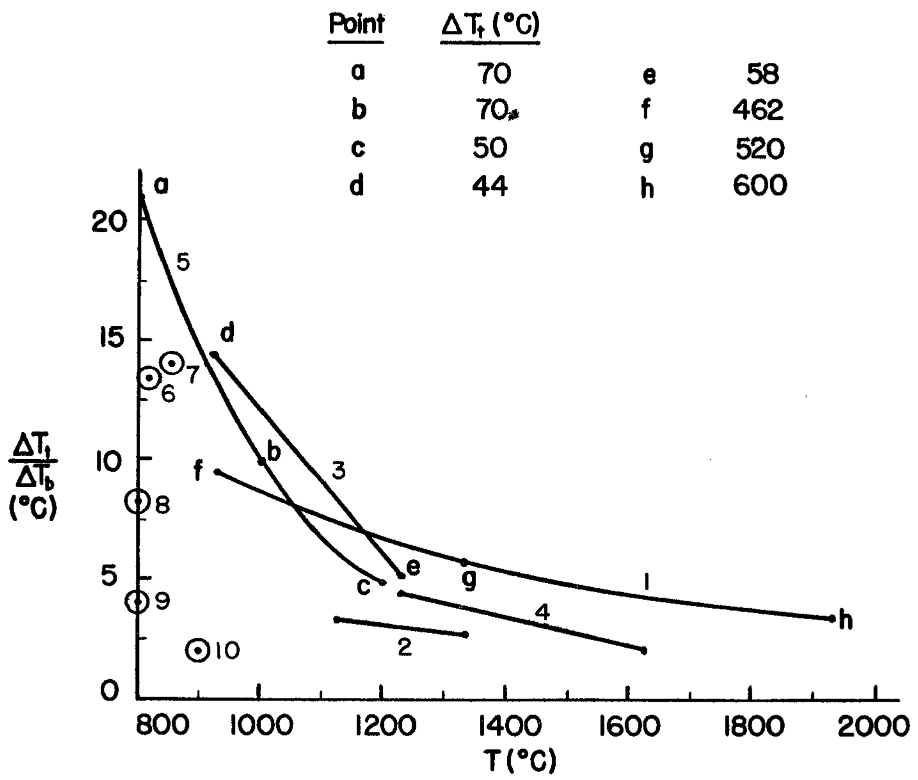
For the purpose of estimating accuracy, it will be assumed that the target source is a blackbody because of the unpredictable magnitude of emittance errors that may be experienced in practice. For the same reason, any errors due to the nature of the environment are not considered. It is important to keep in mind, however, that emittance and environmental problems are often important and can be decisive in the choice of an optimum instrument for a specific application.

Calibration errors result largely from errors in the reference instrument, which usually will be a visually operated optical pyrometer. Lovejoy has estimated the accuracy of a good commercial optical pyrometer under conditions that are apt to prevail in industrial laboratories with reasonably good standards control.[7] This estimate is shown in col. 2 of Table IV. Another source of calibration error is the emittance of secondary calibration sources such as tungsten strip lamps. When other than a near perfect blackbody source is used for calibration because of convenience or necessity, there are bound to be increased calibration errors due to some uncertainty in the source emittance, unless the calibrated and reference instruments are of the same type and have the same spectral parameters. This error should be relatively small for sources that would ordinarily be used for this purpose. (See Eqs. (9) to (11), Eqs. (14) and (15), and col. 3, 7, and 11 of Table IV.) The low total emissivity of tungsten makes it unsuitable as a source for accurate calibration of radiation pyrometers; it is assumed in Table IV that a near blackbody radiator is used for this instrument.



ΔT_b AND ΔT_t VS. TEMPERATURE AND EMITTANCE

FIG. 3



Point	ΔT_t (°C)	Point	ΔT_t (°C)
a	70	e	58
b	70*	f	462
c	50	g	520
d	44	h	600

Curve 1 — Tungsten (approx. same for Mo & Ta)
2 — Cu (molten)
3 — FeO (solid)
4 — FeO (molten)
5 — NiO
6 — Cartridge Brass
7 — Trumpet Brass
8 — Phos. Admiralty Brass
9 — Arsenical " "
10 — 30% CuproNickel "

$\frac{\Delta T_t}{\Delta T_t}$ FOR VARIOUS MATERIALS

FIG. 4

Summarizing the accuracy of automatic radiometric pyrometers:

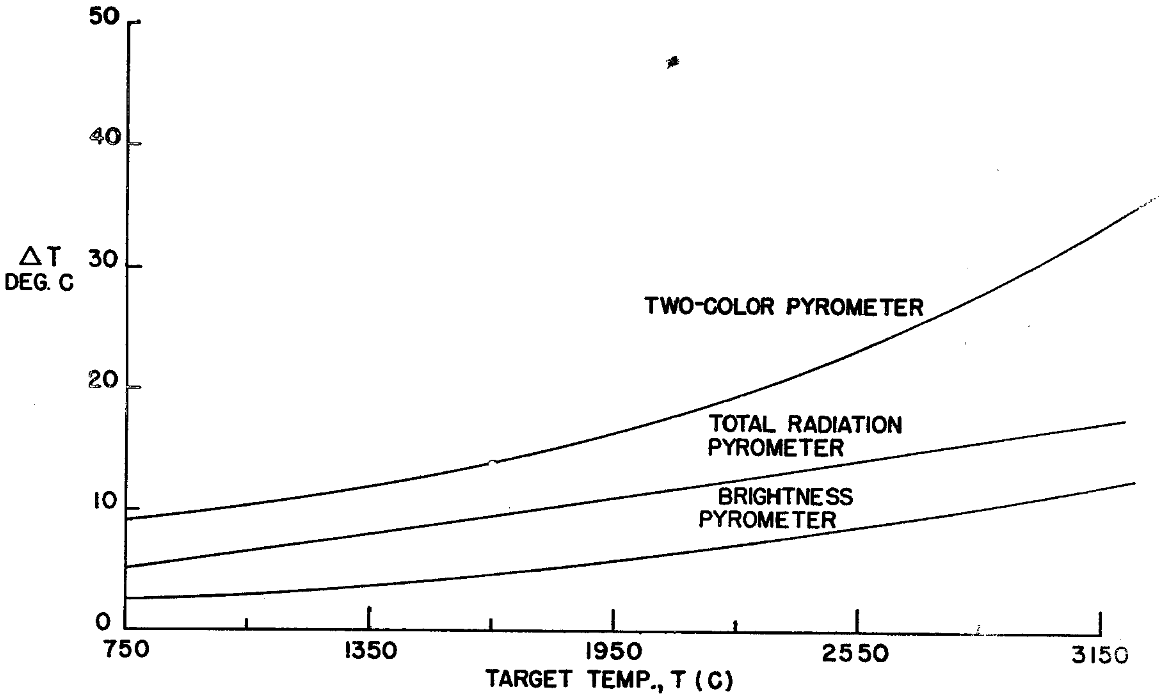
1. The estimated long term accuracies of high performance brightness, total radiation, and two-color pyrometers are 0.4%, 0.7%, and 1.1%, respectively, of the true target temperature, from about 1000° to 3000°K. The errors below 1100°K will be somewhat greater if a blackbody source and thermocouples are not used for calibration. Refer to Fig. 5. Scale errors and those due to target emittance and environmental factors are not included.

2. The estimated short term accuracies, i.e., with the same qualifications but assuming negligible drift errors during the operating period after calibration, are 1/4%, 1/3%, and 1/2% of the actual target temperature, respectively.

EFFECTS OF ENVIRONMENT

The errors in radiometric pyrometry that have been discussed up to now could be quantitatively analyzed and are predictable to some degree. The influence of adverse environmental factors such as ambient radiation and atmospheric dust, smoke, and vapors is so diverse and unpredictable as to make generalization of this source of error very difficult. All these effects are directly analogous to emittance uncertainties, but the uncertainties involved may be of a much higher order.

Dust, smoke, and vapors in the transmission path between source and instrument are a common and serious source of difficulty. In some cases it can be anticipated that the two-color pyrometer will be the least affected. Without previous experience it is not safe to assume this is the case or that errors will be negligible with any



ESTIMATED LONG TERM DRIFT ERRORS

FIG. 1

Table II. Estimated long term drift errors of near ideal automatic radiometric pyrometers.

Column 1	2	3	4	5	6	7	8	9	10	11	12
		Brightness Pyrometer				Total Radiation Pyrometer			Two-Color Pyrometer		
T	T	Error due to $\Sigma dK/K$	Error due to dT_r/T_r	Error due to $d\lambda_e/\lambda_e$	Σ_{rms} 3+4+5	Error due to $\Sigma dK/K$	Error due to dT_r/T_r	Σ_{rms} 7+8	Error due to $\Sigma dK/K$	Error due to $d\lambda_1/\lambda_1+d\lambda_2/\lambda_2$	Σ_{rms} 10+11
°C	°K	°C	°C	°C		°C	°C		°C	°C	
727	1000	0.7	0.8	2.0	2.3	3.8	1.0	3.9	2.5	8.0	8.4
1227	1500	1.6	1.7	3.1	3.9	5.6	1.5	5.8	5.6	8.0	10.0
1727	2000	2.8	3.2	3.3	5.4	7.5	2.0	7.8	10.0	8.0	13.0
2227	2500	4.3	4.8	3.0	7.2	9.5	2.5	9.8	15.5	8.0	17.5
2727	3000	6.3	7.0	2.9	9.9	11.2	3.0	11.6	22.4	8.0	24.4
3227	3500	8.2	9.4	2.3	12.7	13.1	3.5	13.5	30.2	8.0	31.3

Table III. Radiometric temperature measurements on a number of brass alloys.

Alloy No.[a]	Alloy Name[a]	Temperature Range[b]	ΔT_r[d]	ΔT_t[d]	ΔT_b[d]	$\frac{\Delta T_r}{\Delta T_b}$[e]	$\frac{\Delta T_t}{\Delta T_b}$[f]	$\frac{\Delta T_t}{\Delta T_r}$[f]
		°C	(+)°C	(-)°C	(-)°C			
160	Cartridge Brass	750- 880	85/ 55	170/133	10	5.5	13.3	2.4
342	Trumpet Brass	800- 900	31/ 17	175/113	8	2.0	14.0	6.7
363	Phosphorized Admiralty Brass	750- 800	82/ 62	190/140	17	3.7	8.3	2.3
365	Arsenical Admiralty Brass	750- 830	95/ 81	127/ 92	23	3.5	4.0	1.1
620	10% Cupro-Nickel Brass	760-1000	14/ 4	10	4	1.0	2.5	2.5
660	30% Cupro-Nickel Brass	760- 940	15/ 10	10	5	3.0	2.0	0.7
745	Aluminum Brass	760- 920	70-130	170/200	33	4.0	5.6	1.5
1918	(Experimental) Aluminum Brass	740- 860	70-130	170/200	30	4.3	6.2	1.5

[a] Scovill Manufacturing Company, Waterbury, Connecticut.

[b] Measured with C/A and Pt/Rh thermocouples.

[c] Readings unstable between these limits.

[d] Top numbers are measurements immediately after billet reached control temperature. Bottom numbers are steady state measurements after two to four minutes' heating at control temperature.

[e] Steady state measurements only.

[f] Using steady state data only.

[g] Questionable because of importance of small errors.

All measurements taken with samples in open atmosphere.

instrument. Dust, vapor, or smoke particles in long transmission paths can affect the chroma of radiation by selective absorption or dispersion; furthermore, such particles may reflect background radiation into the optics of a two-color pyrometer, compromising its initial advantages.

Ambient illumination reflected by the target surface or by smoke or dust particles will generally cause the largest errors in a two-color pyrometer operating in the visible spectrum. The reason for this is that most sources of ambient light, e.g., sunlight, fluorescent and incandescent lamps, and some gas flames, have a high color temperature; the two-color pyrometer is sensitive to the chroma rather than the absolute magnitude of radiation. A number of cases have been observed where ambient light has caused more than an order of magnitude greater error in a visible spectrum two-color pyrometer than in either a brightness or radiation pyrometer. At object temperatures above about 1000°C it is not likely that the usual levels of ambient illumination reflected from the target will cause significant errors in any radiometric pyrometer. A related phenomenon to which the two-color pyrometer is particularly sensitive is that of irrelevant target radiation due to the presence of impurities or alloy constituents that will emit radiation with characteristic color or line spectra.

The radiation pyrometer is apt to have greater errors as a result of adverse transmission path environments than the other types, particularly when infrared absorbing vapors are present. Under most conditions it will be less sensitive to ambient radiation than the two-color pyrometer.

The dynamic characteristic of the environment may constitute a serious source of noise, making higher speed measurements virtually impossible. The two-

Table IV. Estimated long term accuracy of near ideal automatic radiometric pyrometers.

Column		1	2	3	4	5	6	7	8	9	10	11	12
		Brightness Pyrometer				Total Radiation Pyrometer				Two-Color Pyrometer			
T C	T K	Instability Error (A)	Calibration Error (Ref. Pyrom.)[a] (B)	Emittance Error[c] (C)	Σ Errors rms (D)	(A)	(B)[a]	(C)[d]	(D)	(A)	(B)[a]	(C)[b]	(D)
727	1000	2.3	8.0	0.2	8.6	3.8	8.0	2.5	9.8	8.4	8.0	1.3	12.0
1227	1500	3.9	2.0	0.5	4.4	5.8	2.0	3.6	8.7	10.0	2.0	2.8	10.5
1727	2000	5.4	2.0	0.7	6.1	7.8	2.0	5.0	11.5	13.0	2.0	5.0	14.0
2227	2500	7.2	4.0	0.9	8.6	9.8	4.0	6.3[e]	14.8[e]	17.5	4.0	7.8	21.0
2727	3000	9.9	7.0	1.1	12.5	11.6	7.0	7.5[e]	18.4[e]	24.4	7.0	11.0	28.0
3227[e]	3500	12.7	11.0	1.5	17.1	13.5	11.0	8.8[e]	22.8[e]	31.3	11.0	15.3	37.5

[a] Assuming use of good commercial visual brightness pyrometer as standard instrument.

[b] Assuming 0.01 emittance units error in emittance of tungsten calibration source.

[c] Assuming 3 mu difference in effective wavelength between test and reference pyrometers; tungsten lamp source.

[d] Assuming 1% emittance error in blackbody calibrating source.

[e] Probably higher due to additional calibration source error.

color pyrometer would appear to be immune if the interference in energy transmission is "grey" in nature. Two-color pyrometers designed with electronic feedback computers, however, can be kept in a continuous state of attempting to accommodate to a dynamically changing environment; under these conditions their usefulness may be seriously compromised unless they are heavily damped.

It is evident that there are a large number of variables that can possible be involved in the process environment, and considerable diversity in the form that they may take. Unless appropriate measures are taken in some cases, no radiometric pyrometer will perform satisfactorily. Choice of the optimum pyrometer under a given set of environmental conditions must often be based on previous experience or thorough field testing.

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1

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3

These equations are derived from the Wien or Planck radiation law in accordance with the radiometric technique used.

4

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5

All data presented on brass alloys was measured by the author and J. Cepelak of the Scovill Mfg. Co., Waterbury, Conn., Nov. 18-20 and Nov. 24-25, 1959. Instr. Development Lab., Reference Report No. 50,228, "Automatic Optical Pyrometer (Two-Color) Field Tests at Scovill Manufacturing Company."

6

Other reasons were the lower temperature capability of the brightness pyrometer, its better accuracy, and lower noise level.

7

See Ref. 1-f

List of Illustrations

Fig. 1. Estimated long term drift errors.

Fig. 2. $\frac{\Delta T_r}{\Delta T_b}$ vs. ϵ_e and ϵ_r.

Fig. 3. ΔT_b and ΔT_t vs. Temperature and Emittance.

Fig. 4. $\frac{\Delta T_t}{\Delta T_b}$ for various materials.

Fig. 5. Estimated long term accuracy.