Technical Solutions – *TS100*

Temperature Errors Caused by Change in Product Emissivity

The focus of this article will examine emissivity as the cause of temperature error when using an infrared brightness thermometer. For discussion purposes, all other variables will be negligible. Additional articles will examine optical path transmission, hot backgrounds and the instrument as additional sources of temperature error.

Also, it is important to make note of the changing terminology. The term emittance has been replaced with emissivity. Emissivity is defined as the ratio of radiant energy emitted by a blackbody when both area at the same temperature and under the same spectral conditions.

DO YOU KNOW YOUR TARGET EMISSIVITY?

Infrared radiation thermometer users have wrestled with the term emissivity since this temperature measurement technology was first applied to a process. Users of infrared brightness thermometers have learned that a true target temperature measurement will be achieved only when the correct target emissivity is set on the instrument dial. When the instrument emissivity dial is set incorrectly a temperature error results. The question is, how can we estimate the magnitude of this temperature error?

COMPONENTS OF TEMPERATURE ERROR

Learning that the indicated target temperature may not be the true target temperature is just the beginning of discovery. The following formula represents the total temperature error of a system (ΔT_{SYSTEM}) and the components that contribute to this error.

$$\Delta T_{SYSTEM} = \Delta T_{EMISSIVITY} + \Delta T_{TRANSMISSION} + \Delta T_{BACKGROUND} + \Delta T_{INSTRUMENT}$$

This formula says that the total temperature error is caused by a combination of these components: an emissivity error, a transmission error, a background error and an error in the instrument itself. Each component error may be positive, negative or zero.

The shaded area of this formula represents what are referred to as application errors. These are errors that may be controlled by the instrument user. Improper applications are the primary contributors to the total error. The instrument error is often the smallest part of the total error. To understand temperature errors more completely, each variable component of the formula will be analyzed individually. With care, all of these errors can be reduced to acceptable levels.

EMISSIVITY AND TEMPERATURE MEASUREMENT

How does target emissivity influence the temperature measurement of an infrared thermometer? An instrument is designed to collect the radiation emanating from a target and to measure that radiance quantitatively. The circuitry of the instrument produces a signal voltage from which a temperature is then indicated. This indicated temperature is proportional to the target radiance. Figure 1 illustrates the signal voltage versus the target temperature curves for three targets with different emissivities.

The curve labeled ε = 1.00 represents the signal voltage output when an instrument views a blackbody. The curves labeled ε= 0.50 and ε = 0.25 represent the signal voltage output when the same instrument views targets with lower emissivities. The shape of the latter curves are the same, however, the signal magnitudes are reduced by the emissivities 0.50 and 0.25.

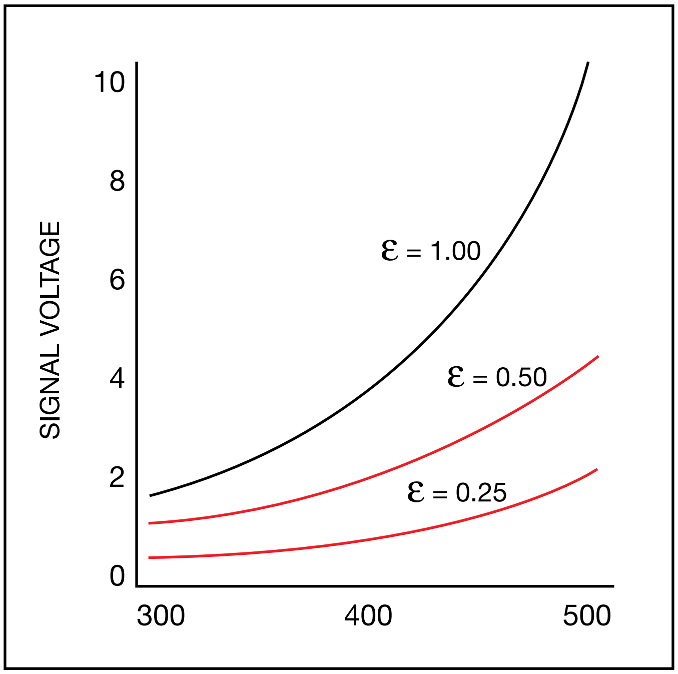

Figure 1
Modline® 4, 43 Series
signal voltage/temperature curves

IRCON®
Fluke Process Instruments

In order for an instruments to indicate true temperature, the emissivity setting must correspond to the target emissivity. This setting is a calibrated gain adjustment which allows the user to trim the instrument to the emissivity of a target. When it is set correctly the instrument indicates the target temperature without error. Figure 2 illustrates the position of the emissivity gain

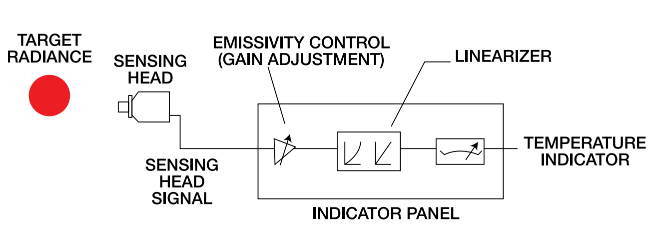

Figure 2

adjustment between the sensing head and the linearizer.

Infrared temperature measuring system illustrating emissivity control

COMPUTE THE TEMPERATURE ERROR

The magnitude of temperature error created by a given emissivity uncertainty depends upon the spectral range of the infrared thermometer and the target temperature. The Error Tables (1°C and 1°F) represent indicated temperature errors caused by 1% emissivity errors. These tables may also be used to compute temperature errors caused by emissivity errors greater than 1%. Reasonable accuracy can be expected with emissivity errors up to 40%.

To compute a temperature error caused by an incorrect

$$\Delta T = -100X \left[\frac{\varepsilon_{DIAL} - \varepsilon_{TRUE}}{\varepsilon_{TRUE}} \right] x \, \Delta T_{TABLE}$$

Example 1

emissivity setting, simply use this formula.

EMISSIVITY DIAL IS SET INCORRECTLY

Calculate the temperature error caused by an emissivity error in measuring steel on the hot strip mill using the Modline 5, 52 Series. The true temperature is 982°C (1800°F) and the ε_{TRUE} is 0.82. An operator mistakenly sets the ε_{TRUE} to 0.70. It will be necessary to interpolate the table for this temperature error.

$$\Delta T = -100X \left[\frac{\varepsilon_{DIAL} - \varepsilon_{TRUE}}{\varepsilon_{TRUE}} \right] x \, \Delta T_{TABLE}$$

$$= -100X \left[\frac{0.70 - 0.82}{0.82} \right] x \, 1.8°F$$

$$\Delta T = 26°F$$

In this example the temperature error would be 26°F (See the summary of symbols below)

Example 2

The following is a summary of the symbols used in the formulas to compute an Indicated Temperature Error.

SYMBOL	DEFINITION
T_{IND}	Target temperature indicated by the instrument
T_{TRUE}	Target temperature
ΔT	Indicated temperature error: $T_{IND} - T_{TRUE}$
ΔT_{TABLE}	Degrees value from body of table 1°C or 1°F
ε_{DIAL}	Emissivity setting on instrumental dial
ε_{TRUE}	True target emissivity

VARIATIONS IN EMISSIVITY DURING A PROCESS RUN

The various paints used on a coil coating line exhibit varying emissivities to the Modline 4, 43 Series. The values range from 0.91 for the vinyls to 0.95 for the polyesters. The operator sets ε_{DIAL} to 0.93, the geometric mean, for all types. All paints are heated to 204°C (400°F). Use the same formula to determine a (±2°F) temperature error for this production run.

The next article in this series (TS101) will explain transmission path variations as a source of temperature errors.

Error Table ºF

Brightness thermometer temperature errors caused by a 1% shift in emissivity (degrees Fahrenheit)

Effective Wavelength	0.65µ	0.9µ	1.6µ	2.3µ	3.4µ	3.9µ	5µ	7.9µ	10.6µ
Model Number	**10P**	**52 72 7V DNS DNE 62UX20P UX60P**	**5G 30 7G 6G UX50P**	**56 46 60**	**43**	**45 75**	**47 77**	**48 78**	**44 74 22 UX40P**
Target Temperature ºF									
0	0.05	0.07	0.13	0.18	0.27	0.31	0.41	0.64	0.86
200	.10	.14	.27	.38	.57	.64	.85	1.3	1.7
400	.18	.25	.46	.66	.97	1.1	1.4	2.2	2.8
600	.28	.38	.70	1.0	1.5	1.7	2.2	3.3	4.1
800	.40	.55	1.0	1.4	2.1	2.3	3.1	4.5	5.6
1000	.53	.73	1.3	1.9	2.8	3.1	4.1	5.8	7.1
1200	.69	.95	1.7	2.5	3.6	4.0	5.2	7.2	8.7
1400	.87	1.2	2.2	3.1	4.5	5.0	6.4	8.8	10
1600	1.1	1.5	2.7	3.8	5.5	6.1	7.6	10	12
1800	1.3	1.8	3.2	4.5	6.5	7.2	9.0	12	14
2000	1.5	2.1	3.8	5.4	7.6	8.4	10	14	16
2200	1.8	2.5	4.5	6.2	8.8	9.7	12	15	17
2400	2.1	2.8	5.2	7.2	10	11	13	17	19
2600	2.4	3.3	5.9	8.2	11	12	15	19	21
2800	2.7	3.7	6.7	9.2	13	14	17	21	23
3000	3.0	4.2	7.5	10	14	15	18	22	25
3500	4.0	5.4	9.8	13	18	19	22	27	30
4000	5.1	6.9	12	16	21	23	27	32	34
4500	6.3	8.5	15	20	25	27	31	36	39
5000	7.6	10	18	23	30	31	36	41	44

For temperature errors caused by shifts in emissivity greater than 1%, use the formula illustrated in the example below.

Instrument	**Modline 5G**
T_{IND}	1000ºF
ε_{DIAL}	0.70
ε_{TRUE}	0.82

$$\Delta T = -100X \left[\frac{\varepsilon_{DIAL} - \varepsilon_{TRUE}}{\varepsilon_{TRUE}} \right] x\ \Delta T_{TABLE}$$

$$= -100X \left[\frac{0.70 - 0.82}{0.82} \right] x\ 1.3^{\circ}F$$

$$\Delta T = 19^{\circ}F$$

To determine T_{TRUE} for this example, use the following formula:

$$T_{TRUE} = T_{IND} - \Delta T$$

$$= 1000^{\circ}F - 19^{\circ}F$$

$$T_{TRUE} = 981^{\circ}F$$

Error Table ºC

Brightness thermometer temperature errors caused by a 1% shift in emissivity (degrees Celsius)

Effective Wavelength	0.65μ	0.9μ	1.6μ	2.3μ	3.4μ	3.9μ	5μ	7.9μ	10.6μ
Model Number	**10P**	**52 72 7V DNS DNE 62UX20P UX60P**	**5G 30 7G 6G UX50P**	**56 46 60**	**43**	**45 75**	**47 77**	**48 78**	**44 74 22 UX40P**
Target Temperature ºC									
0	0.03	0.04	0.08	0.12	0.17	0.20	0.26	0.41	0.54
100	.06	.08	.15	.22	.33	.37	.49	.76	1.0
200	.10	.14	.25	.36	.53	.60	.79	1.2	1.6
300	.15	.20	.37	.53	.78	.87	1.2	1.7	2.2
400	.20	.28	.51	.73	1.1	1.2	1.6	2.3	2.9
500	.27	.37	.68	.96	1.4	1.6	2.1	3.0	3.6
600	.35	.47	.87	1.2	1.8	2.0	2.6	3.7	4.4
700	.43	.59	1.1	1.5	2.2	2.5	3.2	4.4	5.2
800	.52	.72	1.3	1.8	2.7	3.0	3.8	5.2	6.1
900	.63	.86	1.6	2.2	3.2	3.5	4.4	6.0	7.0
1000	.74	1.0	1.8	2.6	3.7	4.1	5.1	6.8	7.8
1100	.86	1.2	2.2	3.0	4.3	4.7	5.8	7.6	8.7
1200	.99	1.4	2.5	3.4	4.9	5.4	6.6	8.5	9.6
1300	1.1	1.6	2.8	3.9	5.5	6.0	7.3	9.3	11
1400	1.3	1.8	3.2	4.4	6.1	6.7	8.1	10	11
1500	1.4	2.0	3.6	4.9	6.8	7.4	8.9	11	12
1600	1.6	2.2	4.0	5.5	7.5	8.1	9.6	12	13
1800	2.0	2.7	4.8	6.5	8.9	9.6	11	14	15
2000	2.4	3.2	5.8	7.7	10	11	13	16	17
2200	2.8	3.8	6.8	9.0	12	13	15	18	19
2400	3.3	4.5	7.8	10	13	14	16	19	21
2600	3.8	5.1	9.0	12	15	16	18	21	23
2800	4.3	5.9	10	13	17	18	20	23	25
3000	4.9	6.6	11	15	18	20	22	25	27

For temperature errors caused by shifts in emissivity greater than 1%, use the formula illustrated in the example below.

Instrument	Modline 5G
T_{IND}	1000ºF
ε_{DIAL}	0.70
ε_{TRUE}	0.82

$$\Delta T = -100X \left[\frac{\varepsilon_{DIAL} - \varepsilon_{TRUE}}{\varepsilon_{TRUE}}\right] x\ \Delta T_{TABLE}$$

$$= -100X \left[\frac{0.70 - 0.82}{0.82}\right] x\ 0.68ºC$$

$$\Delta T = 9.95ºC$$

To determine T_{TRUE} for this example, use the following formula:

$$T_{TRUE} = T_{IND} - \Delta T$$

$$= 500ºC - 10ºC$$

$$T_{TRUE} = 490ºC$$

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