Int. J. Heat Mass Transfer. Vol. 18, pp. 1331–1332. Pergamon Press 1975. Printed in Great Britain

SHORTER COMMUNICATION

SOME GRAY GAS WEIGHTING COEFFICIENTS FOR CO_2–H_2O–SOOT MIXTURES

P. B. TAYLOR and P. J. FOSTER
Department of Chemical Engineering and Fuel Technology, University of Sheffield, Sheffield, S1 3JD, England

(*Received* 6 *January* 1975)

NOMENCLATURE

$a_{m,n}$, gray gas weighting coefficient for a gas–soot mixture;
c, soot concentration [kg/m^3];
$K_{m,n}$, gray gas absorption coefficient for a gas–soot mixture [m^{-1}];
L, path length [m];
p_c, partial pressure of carbon dioxide [atm];
p_w, partial pressure of water vapour [atm];
$q_{1,n}, q_{2,n}$, constants;
$r_{1,n}, r_{2,n}$, constants;
T, temperature [°K];
ε_m, total emissivity of a gas–soot mixture.

WE HAVE shown previously [1] that the emissivity–path length relationship of an isothermal CO_2–H_2O–soot mixture can be represented accurately by a three term gray-gas equation,

$$\varepsilon_m = \sum_{n=1}^{3} a_{m,n}[1-\exp(-K_{m,n}L)], \tag{1}$$

in which the $K_{m,n}$ are independent of the temperature and the temperature dependance of the emissivity is carried by the weighting coefficients, $a_{m,n}$. The constraint that the $K_{m,n}$ be independent of the temperature is essential to the economy of the zone method of calculating radiative transfer because, when it can be applied, the interchange areas which depend upon $K_{m,n}$ and not upon $a_{m,n}$ need be evaluated only once and without prior knowledge of the temperature.

At atmospheric pressure the weighting coefficients, $a_{m,n}$, are a function of four parameters,

$$a_{m,n} = F(c, p_w/p_c, p_c, T),$$

so that extensive tables would be required to represent all those conditions which might be found in combustion chambers. In practice the coefficients may be found from emissivity versus path length data obtained by traversing a radiometer through the furnace or by calculation from the available spectral data for gases and soot. Both approaches are laborious.

In order to provide some limited but readily accessible data, we have calculated [1, 2] the emissivities of CO_2–H_2O–soot mixtures in nitrogen for gas concentrations corresponding to the combustion of oil, $p_w/p_c = 1$, and gas, $p_w/p_c = 2$, at a total pressure of one atmosphere with $p_c = 0{\cdot}1$ atm for combinations of the following values of temperature and soot concentration, $T = 1200, 1500, 1800, 2400$°K and $c = 0{\cdot}0001, 0{\cdot}0005, 0{\cdot}001, 0{\cdot}002\ kg/m^3$, for path lengths from 0·01 to 10 m. A three gray-gas model was fitted to the results using the method described in [1].

At each of the specified soot concentrations it was found [2] that the weighting coefficients $a_{m,n}$ could be represented by a linear function of the temperature within the restricted but practically useful temperature range, $1400 \leqslant T \leqslant 2400$°K, whereby,

$$a_{m,n} = r_{1,n} + r_{2,n} \cdot T, \quad n = 1, 2 \tag{2}$$

and, according to the sum rule [1],

$$a_{m,3} = 1-(a_{m,1}+a_{m,2}).$$

Within this temperature range the error in the representation of the calculated emissivity by equations (1) and (2) was not greater than 3 per cent. Values of the constants $r_{1,n}$ and $r_{2,n}$ are presented in Table 1.

When fitting the gray-gas model, the previously recommended values of $K_{m,n}$ were used [1], given by,

$$K_{m,n} = \exp[q_{1,n} + q_{2,n} \cdot c],$$

excepting that

$$K_{m,1} = 0{\cdot}09 + 500c \text{ when } c \leqslant 0{\cdot}0005\ kg/m^3.$$

For completeness the values of $q_{1,n}$ and $q_{2,n}$ are listed in Table 2.

Table 1. Values of the constants $r_{1,n}$ and $r_{2,n}$ which specify the weighting factors $a_{m,1}$ and $a_{m,2}$ for various soot concentrations applicable in the temperature range 1400–2400°K

Soot concentration c (kg/m^3)	n	$p_w/p_c = 1$		$p_w/p_c = 2$	
		$r_{1,n}$	$r_{2,n}$	$r_{1,n}$	$r_{2,n}$
0·0001	1	0·8119	−0·0000355	0·7191	−0·0000336
	2	0·0280	0·0001013	0·0804	0·0001131
0·0005	1	0·7568	−0·0001676	0·7564	−0·0002182
	2	0·0680	0·0002376	0·0799	0·0002809
0·001	1	0·5478	−0·0001869	0·6123	−0·0002489
	2	0·3846	0·0002071	0·2688	0·0002901
0·002	1	0·5991	−0·0002012	0·7141	−0·0002858
	2	0·3693	0·0002079	0·3313	0·0002386

Table 2. Values of the constants which specify the coefficient $K_{m,n}$ applicable in the temperature range 1200–2400°K

n	$p_w/p_c = 1$		$p_w/p_c = 2$	
	$q_{1,n}$	$q_{2,n}$	$q_{1,n}$	$q_{2,n}$
1	−1·252	558·55	−1·274	590·82
2	−0·221	665·38	−0·233	672·04
3	2·608	839·62	2·452	692·61

Acknowledgement—To Harwell Heat Transfer and Fluid Flow Service for a grant to P. B. Taylor.

REFERENCES

1. P. B. Taylor and P. J. Foster, The total emissivities of luminous and non-luminous flames, *Int. J. Heat Mass Transfer* **17**, 1591–1605 (1974).
2. P. B. Taylor, Radiative emission from flames, Ph.D. Thesis, Univ. Sheffield (1974).