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INFRARED RADIATIVE HEAT TRANSFER IN NONGRAY NONISOTHERMAL GASES

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Abstract—In the present paper, both nongray and nonisothermal behaviors of an infrared emitting-absorbing gas have been taken into account in radiative transfer analyses through the use of the nonisothermal band absorptance. Consideration is given specifically to a simple system consisting of a radiating medium bounded by two infinite parallel black surfaces of different temperatures. Solutions are presented for the cases of radiative equilibrium and combined conduction and radiation. Results based on different methods of evaluating the nonisothermal band absorptance are also compared among themselves. Differences in several fundamental features are exhibited in the nongray nonisothermal solutions as compared to those with nongray but isothermal properties.

NOMENCLATURE

A, total band absorptance of nonisothermal gas [cm^{-1}];
A_{iso}, total band absorptance of isothermal gas [cm^{-1}];
A_0, band width parameter [cm^{-1}];
B_0^2, line width parameter;
b_0, self-broadening coefficient;
C_0^2, correlation parameter [$atm^{-1}cm^{-1}$];
e_1, total black body emissive power [W/cm^2];
e_ω, Planck's function [W/cm^2/cm^{-1}];
e_{ω_i}, Planck's function evaluated at wave number ω_i;
$E_n(t)$, exponential integral of order n;
K, thermal conductivity [W/cm/°K];
k, absorption coefficient;
L, distance between plates [cm];
n, a constant in defining effective pressure p_e;
p_a, pressure of acting gas [atm];
p_N, pressure of inert gas [atm];
q_R, total radiation heat flux [W/cm^2];
$q_{R\omega}$, spectral radiation heat flux [W/cm^2/cm^{-1}];
S, integrated band intensity [$atm^{-1}cm^{-2}$];
T, temperature [°K];
T_c, temperature profile due to conduction alone [°K];
u, dimensionless coordinate, $C_0^2 p_a L$;
y, physical coordinate [cm];
τ_ω, optical coordinate;
ω, wave number [cm^{-1}];
ω_i, band center of ith band [cm^{-1}].

Subscripts
h, equivalent homogeneous quantity;
1, plate at $y = 0$;
2, plate at $y = L$.

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1. INTRODUCTION

RECENT developments of high temperature systems have motivated studies of radiative transfer in an emitting-absorbing gas. Realistic solutions of these types of problems, even in a very simple geometric system, are difficult to obtain because of the frequency- and temperature-dependent radiation properties of the gas. In order to account for the nongray behavior, the modified emissivity [1] or the isothermal band absorptance [2–4] has been employed in the radiative transfer analysis. These treatments, however, are confined to the systems with small temperature variations only, since the temperature dependence of the radiation properties was not considered. To include both nongray and nonisothermal effects in the study of heat exchange in combustion chambers, Hottel and his co-workers [5, 6] have employed a three-gray-band approximation for the total emissivity. On the other hand, in the analysis of a turbulent thermal entrance problem with small radiant perturbation, Nichols [7] has made use of the isothermal band absorptance evaluated at a mean temperature, defined from some simple considerations on the temperature dependence of gaseous absorption characteristics. Mori and Kurosaki [8], and Edwards and his co-workers [9, 10] have also considered radiative transfer in nonisothermal gases by using the spectral absorption coefficient either in its optically thin expression or in its high pressure expression in which line structure effects are neglected. All these analyses, however, have rather restricted ranges of applicability.

It is the purpose of this paper to present a method of calculation which incorporates both nongray and nonisothermal dependences of gaseous radiation properties in radiative transfer analyses for all optical conditions. In order to demonstrate the combined nongray and nonisothermal effects, a simple system consisting of an infrared radiating gas bounded by two parallel black walls is analysed with a large temperature difference across two walls. Solutions of radiative equilibrium and combined radiation and conduction are presented and discussed in detail.

2. ANALYSIS

Nonisothermal band absorptance

Since the basis of the present analysis is the nonisothermal band absorptance, a brief discussion of this parameter, particularly with respect to its applications to radiative transfer analyses, is presented first. Reference should be made to the earlier paper on the formulation of the nonisothermal band absorptance [11]*. The nonisothermal band absorptance is defined as

$$A[T(y'), L] = \int \{1 - \exp[-\int_0^L k[T(y'), \omega] \mathrm{d}y']\} \mathrm{d}\omega \qquad (1)$$

which reduces to the isothermal band absorptance when the temperature along the line of sight is constant, i.e.

$$A_{iso}[T, L] = \int \{1 - \exp[-k(T, \omega) L]\} \mathrm{d}\omega. \qquad (2)$$

It should be noted that, in the study of the radiation properties of nonisothermal gases such as the band absorption and band emission in [11], the mass path length was employed since the mass path length characterizes the number of molecules in the nonisothermal path. However, for infrared radiation transport in most engineering systems, in which pressure is generally constant but temperature and density vary, the geometrical path length is more convenient to use than the mass path length [1, 3, 4]. Therefore, the geometrical path length is used here, and the absorbing gas pressure is assumed constant, but the density variation in the gas is allowed. This is implied, for example, in $T(y')$ of (1).

Existing information about the isothermal band absorptance can be effectively utilized to evaluate the nonisothermal band absorptance by way of the wide-band Curtis–Godson method or the series-expansion method [11]. Even though these methods are not restricted to any particular wide-band model, it is found that Edwards exponential model [12] is especially convenient for actual numerical computations because the correlation parameters are known for most gases. Thus, according to the wide-band Curtis–Godson method, the three equiva-

* Since the completion of this paper, it has been brought to the authors' attention that two formulations similar to the present wide-band Curtis–Godson formulation have been independently developed by R. D. Cess and L. S. Wang at State University of New York at Stony Book and D. K. Edwards and S. J. Morizumi at University of California at Los Angeles.

lent homogeneous parameters A_{0h}, B_{0h}^2 and C_{0h}^2 can be obtained by solving the following equations:

$$C_{0h}^2 A_{0h}^2 = \frac{1}{L}\int_0^L C_0^2 A_0 \,\mathrm{d}y \tag{3}$$

$$C_{0h}^2 A_{0h}^2 = \frac{1}{L}\int_0^L C_0^2 A_0^2 \,\mathrm{d}y \tag{4}$$

$$C_{0h}^2 A_{0h} B_{0h}^2 = \frac{1}{L}\int_0^L C_0^2 A_0 B_0^2 \,\mathrm{d}y. \tag{5}$$

The parameters so obtained will be used in the later calculations for radiative transfer based on the wide-band Curtis–Godson method. For application of the series-expansion method, the evaluation of the nonisothermal band absorptance is rather straightforward, once the Edwards model is chosen [11].

With regard to the application of the nonisothermal band absorptance to radiative transfer calculations under optically thin conditions, it should be noted that the nonisothermal band absorptance in the optically thin limit becomes

$$A = \int_0^L p_a S \,\mathrm{d}y = p_a \int_0^L S \,\mathrm{d}y \tag{6}$$

where S is the integrated band intensity. By expressing the isothermal band absorptance (2) in the same limit

$$A_{\mathrm{iso}} = p_a S L \tag{7}$$

and noting that $S = C_0^2 A_0$, $S_h = C_{0h}^2 A_{0h}$ and (3), it is realized that precisely the same expression as (6) is given by the wide-band Curtis–Godson method, despite the approximate nature of the formulation. Indeed, the validity of this formulation is further confirmed here.

With the help of the nonisothermal band absorptance, it is now possible to have a general systematic formulation of infrared radiative transfer in nongray nonisothermal gases. In the present work, equations of radiative equilibrium and combined conduction and radiation for a simple system are reformulated and solved numerically. The formulation is similar to that of Cess *et al.* [3, 4] except that effects due to nonisothermal radiation properties are included here.

Radiative equilibrium

The system under consideration consists of an infrared radiating gas bounded by two infinite black plates. The plate at $y = 0$ is maintained at temperature T_1 and the other at $y = L$ is T_2, where y is the geometrical path perpendicular to the plates. The total radiative flux is [13],

$$\begin{aligned} q_{\mathrm{R}}(y) &= \int_0^\infty q_{\mathrm{R}\omega}\,\mathrm{d}\omega = e_1 - e_2 \\ &+ 2\int_0^\infty \mathrm{d}\omega \int_0^{\tau_\omega} [e_\omega(t) - e_{1\omega}]\, E_2(\tau_\omega - t)\,\mathrm{d}t \\ &- 2\int_0^\infty \mathrm{d}\omega \int_{\tau_\omega}^{\tau_{L\omega}} [e_\omega(t) - e_{2\omega}]\, E_2(t - \tau_\omega)\,\mathrm{d}t \end{aligned} \tag{8}$$

where

$$\tau_\omega = \int_0^y k[T(y'), \omega]\,\mathrm{d}y'.$$

For radiative equilibrium, q_{R} is constant with respect to y and thus $q_{\mathrm{R}}(y) = q_{\mathrm{R}}(0)$.

Now, if the order of integration is interchanged and the exponential integral function is approximated by an exponential function according to the kernel-substitution technique,

$$E_2(t) \simeq \tfrac{3}{4}\exp(-3t/2). \tag{9}$$

Equation (8) can be written as follows,

$$\begin{aligned} q_{\mathrm{R}}(y) &= e_1 - e_2 + \tfrac{3}{2}\int_0^y \mathrm{d}y' \int_0^\infty \mathrm{d}\omega\, \{e_\omega[T(y')] \\ &- e_{1\omega}\}\, k[T(y'), \omega] \exp\{-\tfrac{3}{2}\int_{y'}^{y} k[T(y''), \omega]\,\mathrm{d}y''\} \\ &- \tfrac{3}{2}\int_y^L \mathrm{d}y' \int_0^\infty \mathrm{d}\omega\, \{e_\omega[T(y')] - e_{2\omega}\}\, k[T(y'), \omega] \\ &\times \exp\{-\tfrac{3}{2}\int_y^{y'} k[T(y''), \omega]\,\mathrm{d}y''\}. \end{aligned} \tag{10}$$

For a radiation spectrum consisting of several vibration-rotation bands, the integration over the entire range of wave number is equivalent to the summation of integrations over these individual bands. In addition, the Planck function in the integrand can be approximated by its value evaluated at each band center. Then in view of the definition (1), equation (10) can be expressed as

$$q_R(y) = e_1 - e_2 + \tfrac{3}{2}\int_0^y \mathrm{d}y' \sum_i \{e_{\omega_i}[T(y')] - e_{1\omega_i}\}\, A_i'[T(y'''), \tfrac{3}{2}(y-y')] - \tfrac{3}{2}\int_y^L \mathrm{d}y' \sum_i \{e_{\omega_i}[T(y')] - e_{2\omega_i}\}\, A_i'[T(y''), \tfrac{3}{2}(y'-y)] \quad (11)$$

where

$$A_i'[T(\sigma), \zeta] = \frac{\mathrm{d}A(T(\sigma), \zeta]}{\mathrm{d}\zeta} \quad (12)$$

$$A_i[T(y'''), \tfrac{3}{2}(y-y')] = \int_{\Delta\omega} \mathrm{d}\omega\, [\![1 - \exp\{-\int_0^{\frac{3}{2}(y-y')} k[T(y'''), \omega]\, \mathrm{d}\eta\}]\!] = \int_{\Delta\omega} \mathrm{d}\omega\, [1 - \exp\{-\tfrac{3}{2}\int_{y'}^{y} k[T(y'''), \omega]\, \mathrm{d}y'''\}] \quad (13)$$

and $y''' = \frac{2}{3}(\eta + y')$, $y'' = \frac{2}{3}(\eta + y)$. The implicit independent variables of each element have been carefully indicated in order to avoid possible confusion when different methods of evaluating the nonisothermal band absorptance are employed. For instance, in accordance with the wide-band Curtis–Godson formulation, the functional form of A is

$$A[T(y'''), \tfrac{3}{2}(y-y')] = A_{\text{iso}}[A_{0h}, B_{0h}^2, C_{0h}^2, \tfrac{3}{2}(y-y')] \quad (14)$$

where from equation (3)

$$C_{0h}^2 A_{0h} = \frac{1}{y - y'}\int_{y'}^{y} C_0^2[T(y''')]\, A_0[T(y''')]\, \mathrm{d}y''' \quad (15)$$

and similar expressions can be obtained from equations (4) and (5). For the Hottel method, which corresponds to a simplified version of the series expansion method [11], there results

$$A'[T(y'''), \tfrac{3}{2}(y-y')] = A'_{\text{iso}}[T(y'), \tfrac{3}{2}(y-y')]. \quad (16)$$

Combined radiation and conduction

In this case, the energy equation is

$$K\frac{\mathrm{d}^2T}{\mathrm{d}y^2} = \frac{\mathrm{d}q_R}{\mathrm{d}y} \quad (17)$$

with the boundary conditions $T = T_1$ at $y = 0$ and $T = T_2$ at $y = L$. Since the present study concerns primarily effects of the nongray nonisothermal radiation properties of the gas on radiative transfer, the thermal conductivity of the gas will be assumed constant, and will be evaluated at the average value of the two wall temperatures. Integrating equation (17) twice with respect to y and applying two boundary conditions, there follows

$$T(y) = T_c(y) + (1/K)\left[\int_0^y Q(\eta)\,\mathrm{d}\eta - \frac{y}{L}\int_0^L Q(\eta)\,\mathrm{d}\eta\right] \quad (18)$$

where

$$T_c(y) = T_1 + (T_2 - T_1)\, y/L \quad (19)$$

$$Q(\eta) = q_R(\eta) - e_1 + e_2 \quad (20)$$

and $q_R(\eta)$ is given in (11). The first term on the right-hand side of equation (18) is the temperature profile due to conduction alone while the last two terms denote the radiation contribution. This contribution can be either positive or negative, depending on local conditions and thermal radiation properties of the gas.

3. NUMERICAL RESULTS AND DISCUSSIONS

The non-linear integral equations (11) and (18) are solved numerically by the method of undetermined parameters. The unknown dimensionless temperature profile is approximated by a Nth degree of polynomial

$$\frac{T - T_1}{T_2 - T_1} = \sum_{i=0}^{N} a_i \left(\frac{y}{L}\right)^i \tag{21}$$

with $(N + 1)$ coefficients to be determined. Each governing equation is applied at $(N + 1)$ values of y, giving $(N + 1)$ simultaneous transcendental equations. The solution of these equations is accomplished by the Newton–Raphson method [14], by which the solution always converges and usually converges very rapidly. Wherever integration is necessary, it is carried out by use of the Gaussian quadrature formula. For the present calculations, the highest degree of polynomial required to yield satisfactory results is the eleventh.

A large temperature difference across the plates was imposed for all computations with $T_1 = 400°K$ and $T_2 = 1500°K$. In all these computations, a correlation of the isothermal band absorptance is needed, and the Tien–Lowder correlation [15] is employed here on account of its simple continuous nature, i.e.

$$A_{iso}(A_0, B_0^2, C_0^2, L) = A_0 \ln\left(uf_2 \frac{u + 2}{u + 2f_2} + 1\right) \tag{22}$$

where

$$u = C_0^2 p_a L, \qquad t = B_0^2 p_e,$$
$$p_e = [(p_N + b_0 p_a)/p_0]^n$$
$$f_2 = 2{\cdot}94\,[1 - \exp(-2{\cdot}6t)]. \tag{23}$$

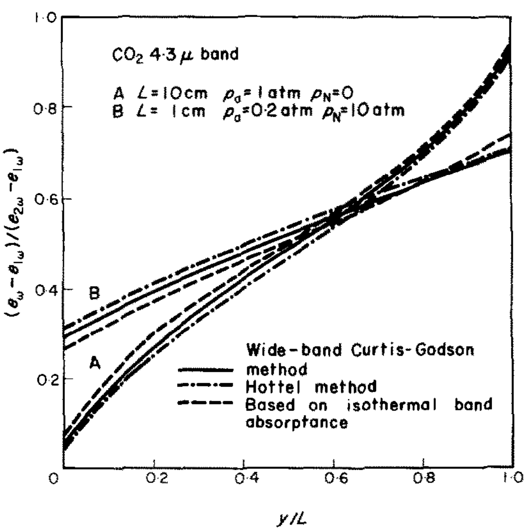

FIG. 1. Temperature profiles of radiative equilibrium.

Figure 1 shows the results of CO_2 gas at radiative equilibrium, based on the three different methods: the wide-band Curtis–Godson method, the Hottel method and the method of using simply the isothermal band absorptance. In the calculation based on the isothermal band absorptance, the reference temperature is taken as the average value of two wall temperatures. Since for CO_2 the 4·3-μ vibration-rotation band is much stronger than other bands, only the 4·3-μ band is considered in the numerical calculations for the sake of simplicity. Two cases representing very different absorption characteristics were selected for numerical comparison. In terms of isothermal band absorptance, Case **B** and Case **A** represent respectively the two asymptotic absorption behaviors: the linear and the logarithmic. For Case A the Hottel method gives the lowest value and the isothermal band absorptance method the highest but the opposite is true for Case B. This peculiar behavior of flipping over, combined with the fact that the wide-band Curtis–Godson results fall in between those of the two other methods, lends further support to the conclusion [11] that the wide-band Curtis–Godson method is more general and accurate than the others.

It is interesting to note that, if only one band is considered in the method of using the isothermal band absorptance, the dimensionless Planck function, $(e_\omega - e_{1\omega})/(e_{2\omega} - e_{1\omega})$, evaluated at the band center is always anti-symmetric with respect to its value at the midpoint $y = L/2$, as can be proved readily from (11).

Similar feature has also been found in the gray solution [13]. However, this is not true when the temperature dependence of radiation properties is taken into consideration. As is shown in Fig. 1, the wide-band Curtis–Godson solution is not anti-symmetric with respect to any point at all. For a gas with several significant vibration-rotation bands, it can be shown from equation (11) that the property of anti-symmetry no longer exists even for the case where isothermal band absorptance is employed.

Table 1. Radiative flux ($-q_R/e_1$) of radiative equilibrium

L (cm)	1	10
Wide-band Curtis–Godson method	195·029	189·481
Hottel's method	195·038	189·491
Method based on isothermal band absorptance	194·887	189·727
Transparent gas	196·754	196·754

Radiative fluxes for these cases shown in Fig. 1 are tabulated in Table 1. These values do not show any significant differences among one another mainly because the gas under consideration is not strongly absorbing and consequently they are all near the limiting value based on a transparent gas. Furthermore, it should be noted that the present analysis and calculations were based on the one-band gas model. In actual applications, especially for large path lengths, not only all fundamental bands must be considered, but also many overtone and combination bands may no longer be negligible. For such cases, significant differences may occur among the resulting fluxes based on various methods of evaluating the nonisothermal band absorptance, but the numerical computation involved will become quite **formidable.**

It might also be expected that the nongray, nonisothermal results should lie somewhere between the two solutions obtained by using the isothermal band absorptance with the reference temperature evaluated, respectively, at two extreme temperatures of the system. This is, however, not always the case. For

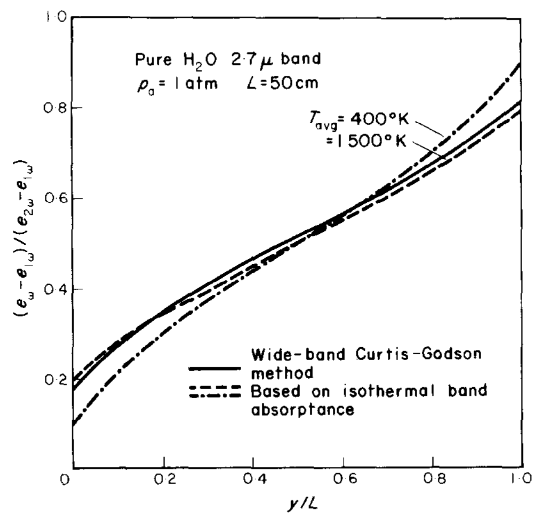

FIG. 2. Comparison between nongray nonisothermal and nongray isothermal solutions of radiative equilibrium.

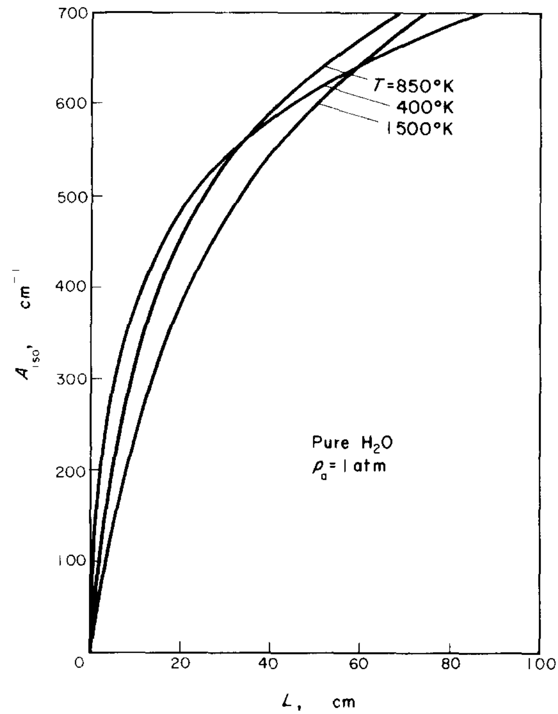

FIG. 3. Isothermal band absorptance of 2·7-μ band of water vapor.

instance, in Fig. 2, which shows the solution of radiative equilibrium for the 2·7-μ band of water vapor, the wide-band Curtis–Godson solution sometimes overshoots the other two solutions. The lack of the anti-symmetric behavior with respect to $y = L/2$ in nongray nonisothermal solutions as shown in Fig. 1 will result indeed in such an overshoot. But, in addition, it should be realized that the value of the isothermal band absorptance evaluated at a given temperature may not even fall into the range bounded by the two values corresponding to a higher and a lower temperature. This is clearly illustrated in Fig. 3.

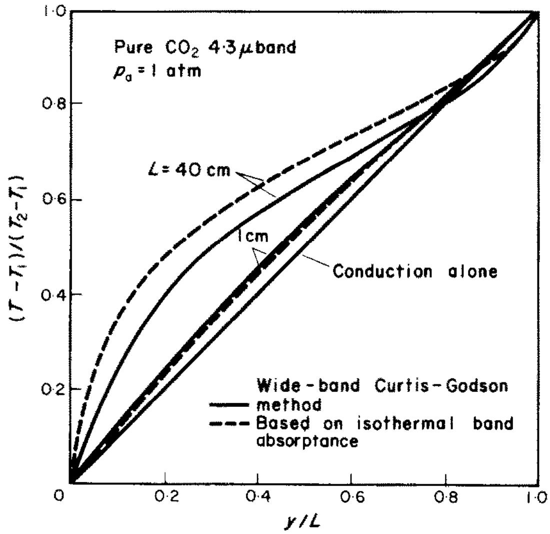

FIG. 4. Temperature profiles of combined conduction and radiation.

For combined conduction and radiation, Fig. 4 shows the result of CO_2 gas based on the wide-band Curtis–Godson method. For comparison the result obtained from the method of using the isothermal band absorptance is also presented. The difference between the two results is more pronounced when the opacity of the gas is increased. It can also be seen that the effect of radiation is to raise the temperature in the cold region and to lower the temperature in the hot region, resulting in an increase of the mean temperature of the system. As is expected, the total heat flux (Table 2) decreases with the increase of opacity.

Table 2. Total heat flux ($-q/e_1$) of combined conduction and radiation

L (cm)	1	40
Wide-band Curtis–Godson method	198·526	187·722
Method based on isothermal band absorptance	198·455	187·980

REFERENCES

1. J. GILLE and R. GOODY, Convection in a radiating gas, *J. Fluid Mech.* **20**, 47 (1964).
2. L. S. WANG, An integral equation of radiative equilibrium in infrared radiating gases, *J. Quant. Spectros. Radiat. Transfer* **8**, 851 (1968).
3. R. D. CESS, P. MIGHDOLL and S. N. TIWARI, Infrared radiative heat transfer in nongray gases, *Int. J. Heat Mass Transfer* **10**, 1521 (1967).
4. R. D. CESS and S. N. TIWARI, The interaction of thermal conduction and infrared gaseous radiation, private communication.
5. H. C. HOTTEL and E. S. COHEN, Radiant heat exchange in a gas-filled enclosure, *A.I.Ch.E. Jl* **4**, 3 (1958).
6. H. C. HOTTEL and A. F. SAROFIM, The effect of gas flow patterns on radiative transfer in cylindrical furnaces, *Int. J. Heat Mass Transfer* **8**, 589 (1965).
7. L. D. NICHOLS, Temperature profile in the entrance region of an annular passage considering the effects of turbulent convection and radiation, *Int. J. Heat Mass Transfer* **8**, 589 (1965).
8. YASUO MORI and YASUO KUROSAKI, Heat transfer by radiation and other transport mechanisms, *Bull. J.S.M.E.* **9**, 560 (1966).
9. S. DE SOTO and D. K. EDWARDS, Radiative emission and absorption in nonisothermal nongray gases in tubes, *Proc.* 1965 *Heat Transf. Fluid Mech. Inst., Los Angeles.* Stanford University Press, Stanford, California (1965).
10. D. K. EDWARDS, L. K. GLASSEN, W. C. HAUSER and J. S. TUCHSCHER, Radiation heat transfer in nonisothermal nongray gases, *J. Heat Transfer* **89**, 219 (1967).
11. S. H. CHAN and C. L. TIEN, Total band absorptance of nonisothermal infrared-radiating gases, *J. Quant. Spectros. Radiat. Transf.* to be published.
12. D. K. EDWARDS and W. A. MENARD, Comparison of models for correlation of total band absorption, *Appl. Optics* **3**, 621 (1964).
13. E. M. SPARROW and R. D. CESS, *Radiation Heat Transfer.* Wadsworth, Belmont, Calif. (1966).
14. J. B. SCARBOROUGH, *Numerical Analysis,* p. 215, 6th ed. Johns Hopkins, Baltimore, Md. (1966).
15. C. L. TIEN and J. E. LOWDER, A correlation for total band absorptance of radiating gases, *Int. J. Heat Mass Transfer* **9**, 698 (1966).

RAYONNEMENT THERMIQUE INFRAROUGE DANS DES GAZ NON GRIS ET NON ISOTHERMES

Résumé— Dans cet article, on tient compte du comportement d'un gaz non gris et non isotherme à l'infrarouge, à la fois absorbant et émettant, à partir de l'utilisation d'une bande d'absorption non isotherme. On prend en considération un système simple consistant en un milieu rayonnant limité par deux surfaces noires parallèles et infinies à températures différentes. On donne des solutions pour des cas d'équilibre de rayonnement et de rayonnement et conduction combinés. Les résultats basés sur différentes méthodes d'évaluation de l'absorption spectrale non isotherme sont aussi, comparés entre eux. Les différences entre plusiers faits fondamentaux sont dégagées à partir des solutions pour un gaz non gris et non isotherme en comparaison avec celles relatives à des propriétés non grises mais isothermes.

WÄRMEÜBERGANG DURCH INFRAROTE STRAHLUNG IN NICHT-GRAUEN, NICHT-ISOTHERMEN GASEN

Zusammenfassung—Im vorliegenden Beitrag werden beim Energietransport durch Strahlung sowohl die nicht-grauen als auch die nichtisothermen Eigenschaften eines Gases, das im Infrarotbereich emittiert und absorbiert, mittels der nicht-isothermen Bandabsorption berücksichtigt. Speziell wird ein einfaches System betrachtet, das aus einem strahlenden Gas zwischen zwei unendlich grossen, parallelen, schwarzen Oberflächen verschiedener Temperatur besteht. Die Lösungen sind angegeben für den Fall des Strahlungsgleichgewichts und den Fall kombinierter Wärmeleitung und Strahlung. Ergebnisse, die auf verschiedenen Auswertemethoden der nicht-isothermen Bandabsorption beruhen, werden auch untereinander verglichen. Die verschiedenen charakteristischen Unterschiede der nicht-grauen und nicht-isothermen Lösungen im Vergleich zu den Ergebnissen für nicht-graue, aber isotherme Verhältnisse werden aufgezeigt.

ТЕПЛОПЕРЕНОС ИНФРАКРАСНЫМ ИЗЛУЧЕНИЕМ В НЕСЕРЫХ НЕИЗОТЕРМИЧЕСКИХ ГАЗАХ

Аннотация—В представленной статье при анализе лучистого теплообмена с помощью неизотермической полосы поглощения учитывается несерое и неизотермическое поведение инфракрасно излучающего и поглощающего газа. Особо рассматривается простая система, состоящая из излучающей среды, ограниченной двумя бесконечными параллельными черными поверхностями при различных температурах. Представлены решения для случаев лучистого равновесия и совместной теплопроводности и излучения. Сравниваются между собой результаты расчета неизотермической полосы поглощения, полученные различными методами. В несерых неизотермических решениях обнаружены некоторые существенные отличия от серых изотермических решений.