Conclusions

A numerical study of buoyancy-assisted mixed convection in a vertical porous channel with asymmetric heating at the walls was performed. The Brinkman-Forchheimer-extended Darcy model was used to account for both the inertia and the viscous effects. The evolution of mixed convection in the entrance region was examined in detail.

The results show that as the Darcy number is decreased while the modified Grashof number and the Reynolds number are kept constant, distortions in the velocity profile (which are stronger in the UWT condition), result in increased velocities near the walls leading to increased heat transfer. For the values of Gr^* and Re considered, heat transfer enhancement in the mixed convection region is more pronounced in the UWT condition. In the fully developed region, for the UWT condition, the asymptotic value of the Nusselt number increases with decreasing Darcy number throughout the entire range of Da, whereas for the UHF condition, the increase in Nusselt number was significant only at high values of Da ($Da \geq 10^{-4}$). In the UWT condition, the average Nusselt number over the entrance region decreases more steeply with Darcy number than in the UHF condition.

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Wideband Spectral Models for the Absorption Coefficient of Water Vapor

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Introduction

THE exponential wideband model developed by Edwards and Menard[1] has been utilized successfully to solve many radiative transfer problems in high-temperature systems, but it is well recognized that this model does not take into account the effect of nonblack walls in radiative transfer calculations.[2] This deficiency may be readily overcome if spectral computations are performed utilizing an appropriate wideband spectral model for the absorption coefficients of participating gases. Desoto and Edwards[3] and Edwards et al.[4] proposed such a spectral model on the basis of the exponential wideband model, and made use of this model to analyze radiative transfer in nonisothermal and nongray gases, but this wideband spectral absorption coefficient was assumed to be only applicable to the overlapped-line case. Recently, another exponential band-envelope model was utilized by Taniguti et al.[5] to solve a radiative equilibrium problem in nongray gases. This model, however, possesses a defect. The calculated total emissivity of an isothermal gas is systematically underpredicted because of the presence of $\tanh(2\eta)$, where η denotes the line overlap parameter, in the expression for the absorption coefficient.

The present study aims at improving these wideband spectral models for infrared gases, particularly water vapor. First, additional parameters are introduced into the above-mentioned spectral models, and then optimally adjusted at various total and partial gas pressures utilizing a least-squares method. Finally, a comparison between two wideband spectral models with optimally adjusted free parameters is made with respect to the total emissivity of an isothermal water vapor layer.

Wideband Spectral Models

Edwards et al.[4] proposed the following wideband spectral model for the absorption coefficient of an infrared gas at high pressures or at high temperatures:

$$\kappa_\nu^{(1)} = (\alpha/K_1\omega)\exp(-\Delta\nu/K_1\omega) \tag{1}$$

where α is the integrated band intensity (cm^{-1}/gm^{-2}), ω is the bandwidth parameter (cm^{-1}) and K_1 is a numerical factor assumed to be 1.0.[4] Furthermore, $\Delta\nu$ is defined as follows: $\Delta\nu = \nu_u - \nu$, for an asymmetric band with upper limit ν_u, $\Delta\nu = \nu - \nu_l$, for an asymmetric band with lower limit ν_l, and $\Delta\nu = 2|\nu - \nu_c|$, for a symmetric band with center ν_c. In the expressions for $\Delta\nu$, ν is the wave number of radiation. As shown later, this model can be utilized with an acceptable accuracy even for nonoverlapped-line cases by appropriately adjusting a value of K_1.

In addition to the above Edwards model, another exponential band-envelope model,[5] which is called the modified Edwards model in the present study, was derived by neglecting the cosine term appearing in Elsasser's band model. The absorption coefficient based on this model is written as

$$\kappa_\nu^{(2)} = (\alpha/\omega)\exp(-\Delta\nu/\omega)\tanh(K_2\eta) \tag{2}$$

where K_2 is a numerical factor equal to 2.[5] Unfortunately, as pointed out earlier, this model underestimates the absorption in comparison with Eq. (1), unless the value of K_2 is increased.

As readily found, when $K_2 \to \infty$, the modified Edwards model is reduced to the Edwards model with $K_1 = 1$, which may be obtained by averaging Elsasser's regular band model with the exponential band-envelope over a mean line spacing d, because

$$\begin{aligned}\kappa_\nu &= \frac{1}{d}\int_{-d/2}^{d/2} \frac{(\alpha/\omega)\exp(-\Delta\nu/\omega)\sinh(2\eta)}{\cosh(2\eta) - \cos(2\pi\nu^*/d)}\,d\nu^* \\ &= (\alpha/\omega)\exp(-\Delta\nu/\omega)\end{aligned} \tag{3}$$

Optimizations of K_1 and K_2

In order to utilize the above-mentioned wideband spectral models under various gas temperatures and pressures, two

Received Dec. 7, 1993; revision received March 17, 1994; accepted for publication May 9, 1994.

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Table 1 Obtained results for K_1 and K_2

Pressure, bar			Minimum		Minimum
Total	Partial	K_1	value of $\sigma^{(1)}$	K_2	value of $\sigma^{(2)}$
1	0	0.897	4.969×10^{-2}	4.657	2.926×10^{-2}
1	0.25	0.966	4.671×10^{-2}	5.059	3.566×10^{-2}
1	0.50	1.009	4.388×10^{-2}	5.555	4.036×10^{-2}
1	0.75	1.039	4.151×10^{-2}	6.432	4.397×10^{-2}
1	1.00	1.059	3.921×10^{-2}	∞	4.652×10^{-2}
5	0	1.084	3.746×10^{-2}	∞	5.092×10^{-2}
5	1.25	1.12	3.17×10^{-2}	∞	5.880×10^{-2}
5	2.50	1.133	2.964×10^{-2}	∞	6.171×10^{-2}
5	3.75	1.137	2.937×10^{-2}	∞	6.291×10^{-2}
5	5.00	1.139	2.962×10^{-2}	∞	6.35×10^{-2}
10	0	1.127	3.143×10^{-2}	∞	6.093×10^{-2}
10	2.50	1.139	2.982×10^{-2}	∞	6.368×10^{-2}
10	5.00	1.140	3.017×10^{-2}	∞	6.429×10^{-2}
10	7.50	1.141	3.038×10^{-2}	∞	6.457×10^{-2}
10	10.0	1.141	3.050×10^{-2}	∞	6.471×10^{-2}
100	0	1.141	3.064×10^{-2}	∞	6.486×10^{-2}
100	25	1.141	3.064×10^{-2}	∞	6.486×10^{-2}
100	50	1.141	3.064×10^{-2}	∞	6.486×10^{-2}
100	75	1.141	3.064×10^{-2}	∞	6.486×10^{-2}
100	100	1.141	3.064×10^{-2}	∞	6.486×10^{-2}

free parameters introduced into the models, i.e., K_1 and K_2, have to be optimally tuned. These parameters are adjusted so that the total emissivity of an isothermal gas layer computed directly from its definition

$$\varepsilon_s^{(j)}(T_i) = \pi \int_0^\infty \frac{[1 - \exp(-p_a L \kappa_\nu^{(j)}/RT_i)] I_{b\nu}}{\sigma T_i^4} \, d\nu \qquad (4)$$

with $P_a L$ being the partial pressure-path length, T_i the gas temperature, and R the gas constant agrees well with the total emissivity evaluated from the wideband absorption A_k, i.e.,

$$\varepsilon_w(T_i) = \pi \sum_k \frac{A_k I_{b\nu_k}}{\sigma T_i^4} \qquad (5)$$

Here, $I_{b\nu}$ represents the blackbody intensity at the wave number ν, while $I_{b\nu_k}$ denotes the blackbody intensity at a representative wave number ν_k of a kth band. It should be noted that the present wideband spectral absorption coefficients are eventually defined by Eq. (4); namely, the free parameters involved in Eqs. (1) and (2) are adjusted so that Eq. (4) holds to be true. Actual values of K_1 or K_2 at various total and partial gas pressures are determined by minimizing the sum of the squares of the difference between $\varepsilon_s^{(j)}(T_i)$ and $\varepsilon_w(T_i)$ at the partial pressure-path length of 400 bar-cm, viz.,

$$\frac{\partial \sigma^{(1)}}{\partial K_1} = 0 \quad \text{or} \quad \frac{\partial \sigma^{(2)}}{\partial K_2} = 0 \qquad (6)$$

where the objective function $\sigma^{(j)}$ is defined by

$$\sigma^{(j)} = \sum_{i=1}^{56} [\varepsilon_s^{(j)}(T_i) - \varepsilon_w(T_i)]^2 \qquad (7)$$

Here, T_i is varied from 250 to 3000 K in increments of 50 K. Optimizations of K_1 and K_2 over a range of PaL were also made as to several cases by utilizing the objective function defined by

$$\bar{\sigma}^{(j)} = \sum_{(PaL)_e} \sum_{T_i} \{\varepsilon_s^{(j)}[T_i, (PaL)_e] - \varepsilon_w[T_i, (PaL)_e]\}^2$$

but it was found that the final results are almost insensitive to the difference in the adopted objective functions. The bands considered in the calculations are the rotational, 6.3-, 2.7-, 1.87-, and 1.38-μm bands of water vapor.

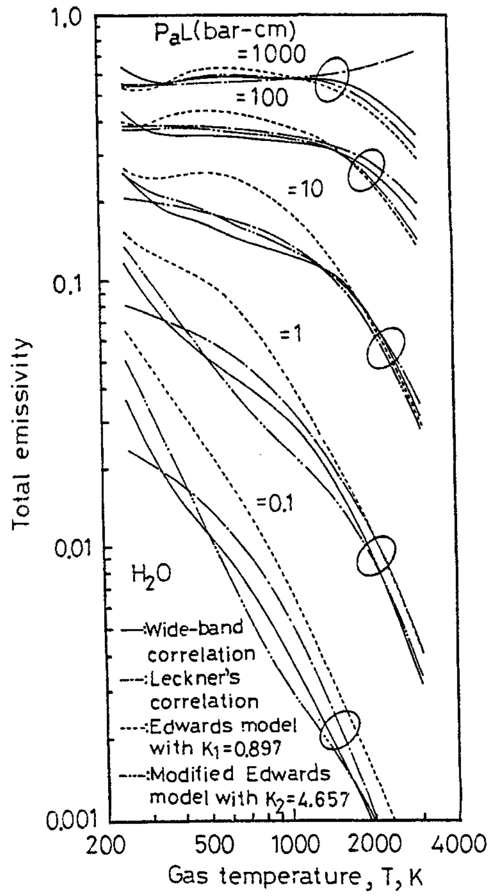

Fig. 1 Total emissivity of water vapor at a total pressure of 1 bar and 0 partial pressure.

Results and Discussion

The determined values of K_1 and K_2 are summarized in Table 1, and the total emissivities computed by making use of the free parameters optimally adjusted for given total and partial pressures are shown in Figs. 1 and 2, where the total emissivities predicted from Leckner's correlation[6] and the wideband correlation are also shown.

From Table 1, it can be seen that the optimum values of K_1 are slightly different from the values given by Edwards

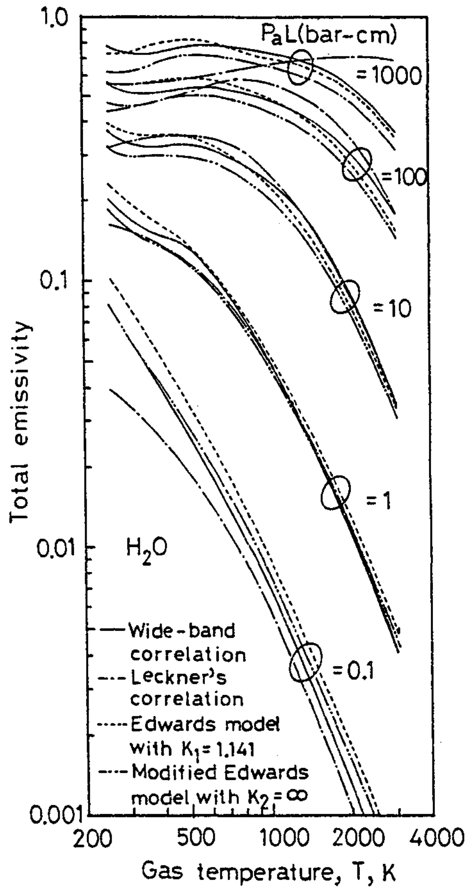

Fig. 2 Total emissivity of water vapor at a total pressure of 10 bar and a partial pressure of 10 bar.

et al.,[4] i.e., $K_1 = 1.0$, whereas the obtained values of K_2 are appreciably greater than 2.

Figure 1 illustrates the total emissivities of water vapor at a total pressure of 1 bar and 0 partial pressure. It is found from this figure that the modified Edwards model is better than the Edwards model, and thus, the modified Edwards model with the optimally adjusted free parameter can be utilized accurately at comparatively low total and partial pressures. However, as seen from Table 1, when an absorbing gas pressure is raised, the reverse is the case even for a total pressure of 1 bar.

Figure 2 depicts the total emissivities at a total pressure of 10 bar and a partial pressure of 10 bar. This figure shows that the predictions by the Edwards model are more accurate than those by the modified Edwards model. As readily understood from Table 1, this is generally true for high total gas pressures.

Finally, it is found that Leckner's correlation[6] becomes less accurate as the partial pressure-path length is increased over about 100 bar-cm.

Conclusions

Free parameters introduced into the two wideband spectral models, i.e., Edwards model and modified Edwards model, for water vapor at various total and partial gas pressures are adjusted so as to obtain better agreement between the total emissivity computed directly from its definition and that evaluated using the exponential wideband model. It is found that the optimum values of the free parameters are different from their originally given values and that, when the free parameters optimally determined for given total and partial pressures are utilized, the Edwards model yields more accurate results in comparison with the modified Edwards model, except for low total and partial pressures. The proposed wideband spectral models for the absorption coefficient are expected to be utilized in solving various radiative transfer problems in nonisothermal and nonhomogeneous media bounded by nonblack walls.

Acknowledgments

The authors wish to acknowledge their sincere gratitude to T. F. Smith and an anonymous reviewer for their valuable comments.

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Finite Element Analysis of the Heat Transfer in Concentric-Tube Heat Exchangers

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Introduction

ALTHOUGH the finite element method has been extensively used for solving structural problems as well as some heat transfer and fluid flow problems, it had never been applied to a heat-exchanger system until Mikhailov and Ozisik[1] reported their analysis using this method. Nevertheless, instead of solving energy equations for fluid flows, they assumed the overall heat transfer coefficient was given, and was a constant such that they could obtain the relationship between element heat transfer rates and nodal temperatures. Hence, their basic principle was the same as those of the classical log-mean-temperature-difference (LMTD) and the number of transfer units (NTU) methods, which only solve the thermodynamic part of the problem. Furthermore, these classical methods assume that the heat transfer is only in the radial direction for the purpose of evaluating the overall heat transfer coefficient; however, the heat transfer is also inconsistently assumed to be in the radial direction only in these methods when it comes to estimate the actual temperature variation. In the light of these shortcomings, the objective of this Note is to apply fundamental principles in physics to heat exchangers by solving the problem of momentum and energy coupling in fluids, as well as the problem of heat conduction in solid bodies simultaneously. Both the parallel-flow configuration

Received Sept. 9, 1993; revision received March 23, 1994; accepted for publication March 30, 1994.

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