SYNOPTIC: Nongray Radiative Heat Transfer in High-Temperature Nonisothermal CO_2-N_2 Mixtures,

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Radiation and Radiative Heat Transfer; Atomic, Molecular, and Plasma Properties

Theme

The paper presents results of an analytical evaluation of nongray equilibrium radiative heat transfer to the stagnation point of a blunt body entering a CO_2–N_2 atmosphere. The relative contributions of the CN and CO(4+) band systems to the radiative emission and the effect of CO(4+) band absorption on the surface flux are discussed. An approximate absorption model for the molecular band absorption coefficient is also described.

Content

The analysis is focused primarily on the radiative transport problem, but utilizes thermodynamic property profiles obtained from an approximate flowfield solution; so that the surface radiative flux predictions reflect the influence of viscosity, conductivity, dissociation, and ionization. Previous theoretical (and experimental) studies only examined the radiative emission from samples of CO_2–N_2 gas mixtures having essentially a uniform temperature. Integrated values of the important radiative quantities are obtained numerically employing the assumption of local thermodynamic equilibrium. The radiative transport processes included are photoionization of neutral and singly ionized C, N, and O atoms; free-free electron interactions; and molecular band transitions (11 band systems are considered).

For molecular transitions, three approximate absorption models that smooth out the detailed vibrational-rotational structure, but retain the essential average characteristics of the band absorption curve, are developed and compared with the more exact smeared rotational line model. From these comparisons, conditions are deduced that enable one to determine from an examination of the spectroscopic constants the band systems for which the models provide a good representation to the absorption curve.

The study indicates that major radiation sources are the CN red, violet, and CO(4+) band systems which contributed 80% or more of the total radiation for the 50% CO_2–50% N_2 atmospheres investigated. At frequencies below $h\nu = 6$ ev, the radiation is optically thin and is governed by the inviscid portion of the shock layer. At larger frequencies, the flux is greatly attenuated, due to strong absorption by the CO(4+) band, and is extremely sensitive to temperature variations in the shock-layer region near the body surface. Because it fails to account for this temperature dependence, an isothermal calculation can significantly overestimate the wall radiative flux. The following table summarizes some typical results and displays the range of flight conditions, body sizes, and CO_2–N_2 mixtures investigated. The large differences appearing in the isothermal column are only due to absorption because the degree of radiative cooling was small for the indicated conditions.

Table 1 Relative influence of the CN and CO(4+) band systems on the radiative flux[a]

				Ratio of wall flux with the indicated change to that without the change[b]			
Mixture CO_2–N_2	U_∞, fps	ρ_∞/ρ_0	R_N, ft	CN bands omitted		CO(4+) band omitted	Isothermal calculation
50–50	26,000	10^{-2}	1	0.645		0.415	...
				0.787[c]			
					0.060[d]		
			2		0.079[d]		1.49
			5		0.103[d]		1.35
50–50	26,000	10^{-3}	2	0.718		0.210	1.54
90–10	32,000	10^{-3}	2	0.984		0.107	2.22

[a] $T_w = 1000°K$.
[b] The standard of comparison is the flux computed for the nonisothermal shock layer with all radiative transport processes included.
[c] Represents omission of CN violet system only.
[d] Represents omission of both the CN and CO(4+) bands.