THE MACROSCOPIC EQUATIONS FOR SIMULTANEOUS HEAT AND MASS TRANSFER IN ISOTROPIC, CONTINUOUS AND CLOSED SYSTEMS

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Summary
In the literature concerning the phenomenological theory of heat and mass transfer in multicomponent systems various formulations of the macroscopic equations are found. In order to decide which formulations are correct, a more or less complete survey of the macroscopic equations is given. Since no disagreements exist concerning the ultimate formulation of the equation of motion, special attention is given to the diffusion equations and the thermal energy equation. The ultimate formulation of the latter equation given in the present paper differs in some details from that found in the literature, the difference being caused by the effect of the diffusing heat capacities and by the dependence of the enthalpy on the concentration. In order to find a proper driving force for the mass transfer, use is made of formulae taken from the thermodynamics of irreversible processes. It appears that for binary systems the barycentric description of the diffusion is the most suitable, especially when convection phenomena play an important role. For multicomponent systems it seems better to relate the diffusion fluxes to the activity. In this case Maxwell's diffusion laws are easily obtained, showing that relations, hitherto only derived in a first approximation for ideal gases, are generally valid for ideal as well as non-ideal systems. From the exact relations simplified descriptions of the diffusion may be derived. If it is, for instance, assumed that Maxwell's diffusion coefficients are all equal and that the system is ideal, then diffusion equations can be derived which are analogous to those for binary systems. In addition, a simplified version of the thermal energy equation is indicated, which differs somewhat from that given by Spalding and Emmons.

List of symbols

- \( a_i \) = activity of component \( i \)
- \( c_i \) = fractional mass concentration
- \( c^*_i \) = fractional number concentration
\( C_{ij} \) = coefficient of diffusion resistance
\( C_p \) = specific heat capacity of the system for constant pressure
\( C_{p,i} \) = partial specific heat capacity of component \( i \) for constant pressure
\( C_{p,i*} \) = molar heat capacity of the system for constant pressure
\( C_{p_{i*}} \) = partial molar heat capacity of component \( i \) for constant pressure
\( \mathbf{d}_i \) = vector for binary systems defined by (70) and for multicomponent systems defined by (102)
\( \mathbf{d}_{i*} \) = vector for binary systems defined by (77) and for multicomponent systems defined by (96)
\( D_{ij} \) = binary diffusion coefficient
\( D_{ij}^T \) = thermal diffusion coefficient
\( D_{ij,m} \) = multicomponent diffusion coefficient
\( \mathbf{e} \) = specific internal energy of the system
\( F_i \) = exterior force exerted on a unit mass of component \( i \)
\( h \) = specific enthalpy of the system
\( h_i \) = partial specific enthalpy of component \( i \)
\( I \) = unit tensor of second order
\( J_i \) = barycentric mass flux of component \( i \)
\( J_{i*} \) = molar number flux of component \( i \)
\( J_q \) = barycentric heat flux
\( K_i \) = mass of component \( i \) created by chemical reactions per unit volume and unit time
\( K_{i*} \) = quantity being defined by (18)
\( l_{T,i} \) = partial latent heat of component \( i \) defined by (32)
\( L_T \) = latent heat of the system defined by (35)
\( L_e \) = Lewis number
\( m \) = mean molar mass of the system
\( m_i \) = molar mass of component \( i \)
\( n \) = total number of moles per unit volume
\( n_i \) = number of moles of component \( i \) per unit volume
\( N \) = number of components
\( p \) = hydrostatic pressure
\( q \) = reduced heat flux
\( Q_p \) = heat of reaction for constant pressure, measured per unit time and unit volume
\( R_A \) = molar gas constant of Avogadro
\( i \) = time
\( T \) = absolute temperature
\( v \) = specific volume of the system
\( v_i \) = partial specific volume of component \( i \)
\( \mathbf{v} \) = mass velocity
\( \mathbf{v}^* \) = number velocity
\( \mathbf{v}_i \) = velocity of component \( i \)
\( \mathbf{V}_i \) = diffusion velocity of component \( i \)