THERMAL AND CALORIC EQUATIONS OF STATE FOR NITROGEN IN A WIDE RANGE OF DENSITY AND TEMPERATURE: APPLICATION TO CALCULATION OF CRYOGENIC JET INJECTION

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Abstract: An analytical equation of state (EoS) of a real gas for nitrogen is developed. The applicability domain of the EoS was verified in a wide range of density (from 0 to the value at the triple point) and temperature (from 100 to 5000 K). The obtained EoS is introduced into the gasdynamic code for calculating multidimensional turbulent reactive flows. Using the new EoS, the outflow of a dense flooded turbulent jet of cryogenic nitrogen into a chamber filled with nitrogen at normal temperature has been performed. The calculation results are compared with available experimental data on the density variation in the jet. Satisfactory agreement was obtained between the results. The developed EoS makes it possible to separate the regions with liquid and gas states in the jet flow based on the local instantaneous values of density and temperature in the jet without using a two-phase flow model.

Keywords: nitrogen; real gas; wide range equation of state; triple point; cryogenic jet; density distribution

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Figure Captions

Figure 1 Comparison of calculation results using Eq. (5) (curve) with tabulated data [17] (symbols) on the saturation line of nitrogen

Figure 2 Comparison of the saturation line for nitrogen $P_S(\rho)$ calculated based on Eqs. (18) (curve) with tabulated data [17] (symbols): *1* — gas; and *2* — liquid

Figure 3 Comparison of the self-similar dependence (21) (curve) with the tabulated values (symbols) on different isotherms: *1* — $T = 300$ K; *2* — 400; *3* — 500; *4* — 600; *5* – 700; and *6* — $T = 800$ K

Figure 4 Comparison of calculated (curves) and tabulated [17] (symbols) dependences of the nitrogen specific heat C_v on density in the domain of supercritical fluid on different isotherms: *1* — $T = 300$ K; *2* — 400; *3* — 800; *4* — 1000; and *5* — $T = 1200$ K

Figure 5 Schematic of the computational domain: (*a*) side view; and (*b*) exploded view from the nitrogen injector channel

Figure 6 Comparison of the calculated (*1*) dependences $C_p(T)$ (*a*), $\rho(T)$ (*b*), $E(T)$ (*c*), $\eta(T)$ (*d*), and $\lambda(T)$ (*e*) with data [25] (*2*) for nitrogen on isobar 3.98 MPa

Figure 7 Calculated fields of nitrogen density in the longitudinal cross section of the computational domain obtained for sets of initial conditions I (*a*) and II (*b*)

Figure 8 Comparison of calculated (curves) and measured [3] (symbols) profiles of nitrogen density along the spray axis for sets of initial conditions I (*a*) and II (*b*)

Figure 9 Comparison of calculated (curves) and measured [3] (symbols) distributions of reduced nitrogen density ρ^+ on the reduced radius $r/r_{1/2}$ at different distances from the injector nozzle X/D for the set of conditions I: *1* — $x/D = 1.2$; *2* — 5; *3* — 10; *4* — 15; *5* — 20; and *6* — $x/D = 25$

Table Captions

Table 1 Values of coefficients in Eqs. (8) and (9)

Table 2 Polynomial coefficients in Eqs. (18) for approximation of nitrogen pressure on the saturation line

Table 3 Values of coefficients in Eqs. (19)–(21)

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