

Equations of State for New Refrigerants, Hydrocarbons, and Hydrofluoroethers

Y. Kayukawa ^{C, S}, M. Hasumoto and Y. Kano

School of Science for Open and Environmental Systems, Keio University, Yokohama, Japan

K. Watanabe

Department of System Design Engineering, Keio University, Yokohama, Japan

Two equations of state (EoS), liquid-phase EoS and virial EoS for environmentally-friendly refrigerants, hydrocarbons (HCs) including propane, n-butane, isobutane, and hydrofluoroethers (HFEs) including trifluoromethyl methyl ether and pentafluoroethyl methyl ether are presented. We have employed our experimental results obtained with a newly constructed rapid density-measurement system with the aid of a vibrating-tube densimeter as input data for EoS. The experimental range of the system is 240 - 380 K for temperature and up to 7 MPa for pressure, respectively. Measurements are available both in liquid-phase and gas-phase for pure components, but limited in liquid-phase for mixture samples. Saturation properties such as vapor-pressures (bubble-point pressures for mixtures) and saturated-liquid densities were also obtained. The experimental uncertainties were evaluated to be 0.07 kg/m³ or 0.024 % whichever was greater for densities, 0.26 kPa or 0.022 % whichever was greater for pressures, and 3 mK for temperatures, respectively. These experimental results contain the first report of thermodynamic properties for HCs and HFEs, especially for HC mixtures. In order to offer systematic information to interpolate the present experimental results, therefore, we aimed to develop some EoS to represent the thermodynamic properties obtained with our measurement system. Liquid-phase EoS has a functional form proposed by H. Sato in 1981 for water, and we have applied its basic function to represent the thermodynamic properties for pure HCs and HFEs up to 20 MPa for pressures and 240 K - 0.95 T_C [critical temperature] for temperature. The new mixing rule for this EoS to represent PVTx properties of the binary and ternary HC systems with the binary interaction parameter, k_{ij} , is also discussed. For the gas-phase PVT properties, truncated virial EoS with well established functional forms of temperature for virial coefficients was also developed. Regarding these thermodynamic models for liquid-phase and gas-phase, some derived properties including heat-capacities and speeds of sound were also calculated from the models, to confirm the thermodynamical soundness of the models. By using these models and a couple of correlations for vapor-pressures and saturated-liquid densities to create the artificial input data, multi-property EoS in terms of Helmholtz-energy function for trifluoromethyl methyl ether was also developed.