Summary

Reliable humidity measurement is attracting an increasing interest due to its crucial role in the industry, meteorology, pharmaceutical manufacturing, electronics, food industry and air conditioning. Metrological traceability to SI through appropriate humidity standards is a key to the reliability needed in these applications. This work addresses improved humidity standards by developing new calculation methods and calibration systems and methods.

Any conversion between humidity quantities should consider a correction for the matrix effect, i.e. the interaction of water molecules with carrier gas, known as the water vapor enhancement factor. The direct measurement of the enhancement factor requires costly experiments; in contrast, current work provides a new functional equation and several sets of the coefficients by exploiting different approaches and the currently available data from the literature. The equation is founded on two mole fraction-related factors calculated based on the intermolecular potential, Helmholtz free energy, excess properties, quantum chemistry and existing experimental data. Correlations are reported for air, nitrogen, oxygen, ammonia, hydrogen, methane, argon and carbon dioxide. Four different correlations of air-water mixture exhibit a fairly good agreement within their uncertainty deviating within $4 \cdot 10^{-4}$ from the well-known Greenspan equation in the temperature range from 40 °C to 140°C and pressure up to 0.6 MPa.

Some seventh of the total energy consumption in the European Union is contributed by the industrial drying processes. Relative humidity (RH) sensors, as the most widely-used process control indicators, cannot provide traceable measurements above 100 °C due to the lack of standards causing an over dry estimated to cost 30 million euros per annum[1]. Current work introduces a humidity generator based on SI-traceable mixing of the air and water vapor exploiting a quasi-spherical microwave resonator (QSR) as a reference for dew-point temperature up to 140 °C and pressure up to 0.6 MPa. The humidity of the generated reference flow is then defined, self-consistently, by the specific humidity estimated from the mass flow of water and air, water vapor mole fraction by exploiting the QSR and the dew-point temperature having a chilled mirror hygrometer(CMH) in its operating range. The generator is integrated into a calibration sub-chamber accommodated in a climatic temperature-controlled chamber. The expanded uncertainty (k=2) of the water vapor mole fraction is U_X=0.004 at x=0.2 increasing to U_X=0.014 at x=0.8.

Discrete steady-state calibration of RH sensors is extremely time-consuming in comparison with other physical quantities. An alternative method is introduced in this work by recovering the conventional definition of the calibration correction for the linear changes of the measurand in the second order systems based on the Laplace-domain studies. The additional uncertainty contributions are also reported for the time delay, linearity, temperature variations and differentiation of the signal. As a consequence, the calibration curves and their confidence intervals can be calculated through a data fusion method by employing the density function grids. A two-dimensional calibration strategy is also proposed. Moreover, a humidity calibrator is designed based on numerical simulations and prototyped with unique features which appropriate non-static calibration needs.

A neural network-based uncertainty algorithm (NNUA) is introduced for generic multi-input multi-output, nonlinear and computationally expensive mathematical models. The algorithm iteratively converges to the best estimate, variance and the confidence interval values guaranteed to match that of the adaptive Monte-Carlo (AMC) algorithm for the requested number of significant digits in a much more computationally efficient way. A worked example confirms that the NNUA operates 6800 times faster for an iterative simultaneous system of equations.