Effect of gas imperfection on humidity measurements

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It was found experimentally that the deviation of the water vapor mole fraction in compressed nitrogen from that predicted by the ideal gas law achieves 42% at the pressure of 10 MPa and the temperature from 10 to 100°C. The temperature and pressure dependence of the enhancement factor of moist nitrogen was obtained. The difference between the enhancement factors of moist nitrogen and air was estimated to be within the experimental errors.

Water vapor is a very important constituent of the Earth's atmosphere that governs the formation of clouds and precipitation, as well as radiative transfer and affects the climate. Besides, air humidity is one of the basic weather parameters. Among the most urgent problems in developing systematic aerological measurements, a particular place is given to meteorological provision of measurement facilities used, and an important element of this provision is adequacy of technical characteristics of optical instruments operating in the free atmosphere and under laboratory conditions, at which measurements are usually conducted with the use of nitrogen.

The partial saturation pressure above a plane water surface $e(t)$ for the case of an ideal gas is tabulated in psychrometric tables for different temperatures. In a real gas, when measuring the mole fraction x of gas humidity, it is necessary to introduce some corrections depending on pressure and temperature. The enhancement factor f has received wide acceptance for estimating the deviation of the water vapor mole fraction in a real gas from the ideal-gas model. In this case, the water vapor mole fraction x is calculated as

$$x = fe(t)/P , \qquad (1)$$

where P is the gas pressure; $e(t)$ is the water vapor pressure at the temperature t.

The aim of this work was to study the enhancement factor of moist nitrogen that characterizes the deviation of the water vapor mole fraction in a real gas from that calculated for the ideal gas model at the pressure up to 10 MPa and temperature t from 10 to 100°C.

Experimental studies of the enhancement factor of moist nitrogen were conducted on an UVT 103-A-2001 highest-accuracy setup[1] developed and certified in the East-Siberian R&D Institute of Physical-Technical and Radio Technical Measurements and registered at the R&D Institute of Metrological Service. The relative error in determination of the enhancement factor did not exceed ±1.5% at the confident probability of 0.95. This setup produces a gas with metrologically justified values of humidity at the temperature ranging from 0 to 60°C and pressure from 0.1 to 10 MPa.

A gas from an external source flows through a high-pressure stabilizing system to a saturator, where it is saturated with water vapor. Then a restrictor decreases the gas pressure down to a needed level, and the gas comes to the external measurement facility – hygrometer, which measures the water vapor mole fraction. The saturator and restrictor are placed in a water bath maintained at a constant temperature.

After processing jointly our experimental data and the results from Refs. 2–5, we determined the pressure and temperature dependences of the enhancement factor of moist nitrogen. As can be seen from Fig. 1 and Table 1, in the considered pressure and temperature range the deviation of water vapor mole fraction in real nitrogen from that for the ideal gas achieves 42 %.

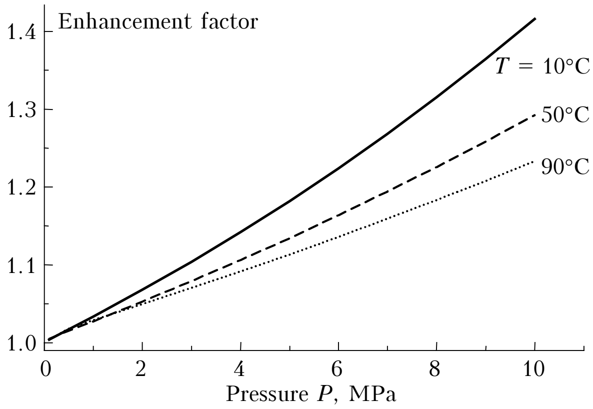

Fig. 1. Pressure dependence of the enhancement factor of moist nitrogen.

Thus, the effect of gas imperfection is stronger at low temperature and high pressure, and this

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should be taken into account in practical measurements of gas humidity.

Since the experimental data on the nitrogen enhancement coefficients determined with metrologically justified values are unavailable in the literature, it is interesting to compare them with the literature reference data on humid air,[6] especially, keeping in mind that nitrogen makes up the major part of air.

Table 1. Enhancement factor of moist nitrogen

Pressure P, MPa	Temperature, °C				
	10	30	50	70	90
0.1	1.0039	1.0043	1.0052	1.0060	1.0040
0.5	1.0169	1.0155	1.0153	1.0163	1.0182
1	1.0334	1.0296	1.0276	1.0274	1.0289
2	1.0678	1.0588	1.0529	1.0498	1.0495
3	1.1039	1.0893	1.0791	1.0729	1.0703
4	1.1419	1.1211	1.1063	1.0967	1.0916
5	1.1819	1.1542	1.1345	1.1213	1.1133
6	1.2240	1.1889	1.1638	1.1467	1.1359
7	1.2684	1.2251	1.1942	1.1728	1.1592
8	1.3150	1.2629	1.2258	1.2002	1.1832
9	1.3643	1.3024	1.2587	1.2283	1.2079
10	1.4161	1.3438	1.2928	1.2574	1.2334

It can be seen from Table 2 that the deviation between the results does not exceed real experimental error. This fact was also noticed at negative temperatures in Ref. 7.

Table 2. Relative difference (δf, %) in the enhancement coefficients for moist nitrogen and humid air

Pressure P , HPa	Temperature, °C				
	10	30	50	70	90
0.1	–	0.01	0.01	-	-
0.5	0.02	0.03	0.03	0.04	0.04
1	0.04	0.06	0.07	0.08	0.09
2	0.17	0.14	0.16	0.17	0.20
4	0.34	0.36	0.39	0.43	0.43
6	0.74	0.75	0.76	0.67	0.70
8	1.30	1.2	1.1	1.1	1.0
10	1.9	1.8	1.6	1.5	1.4

Thus, the data obtained solve the problem on estimating and accounting for nonideality of real moist nitrogen.

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