

Magnetic stage with environmental control for optical microscopy and high-speed nano- and microrheology.

Supplementary Material

Pavel Aprelev, Bonni McKinney, Chadwick Walls, and Konstanin G. Kornev

Department of Materials Science and Engineering, Clemson University, Clemson, South Carolina, USA, 29634. E-mail: kkornev@clemson.edu

SUPPLEMENTARY MATERIAL 1 – SUPPLY SYSTEM FOR NITROGEN GAS - WATER VAPOR MIXTURE

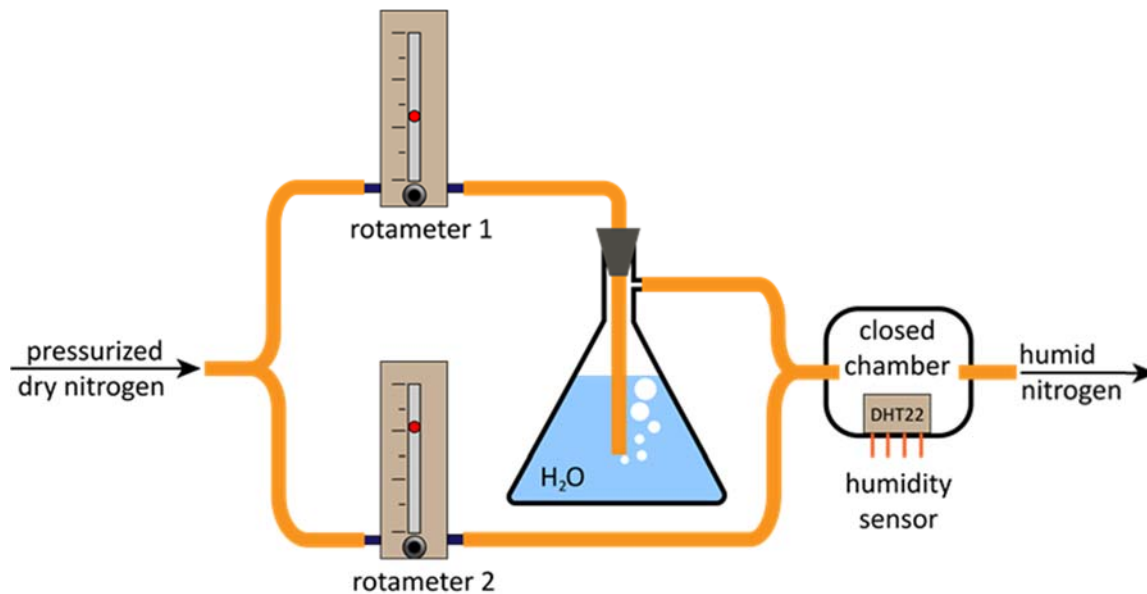


Figure S.1. A schematic of the supply system of nitrogen of controlled humidity with a humidity sensor.

To supply the nitrogen/water vapor mixture of controlled humidity to the environmental chamber, the design of Ref.² was adapted to our case (Figure S.1). Initially, a pressurized dry nitrogen gas is split between two rotameters that allow for manual control of the flow through them. The gas that is

fed through one rotameter is fed into a sealed flask and is bubbled through a deionized water reservoir to reach a saturation humidity. It is then mixed with dry gas fed through the second rotameter and led into a sealed chamber, where a humidity sensor (HIH-3040, Sparkfun) measures its humidity. The HIH-3040 humidity sensor was calibrated on the aqueous glycerol solutions of known concentrations according to the tabulated values of humidity.³ By changing the relative flow through the two rotameters and reading the measured humidity from the sensor, one gains a complete control of the humidity of the fed nitrogen gas. Finally, the nitrogen gas of known humidity is fed to the environmental chamber with the sample. Due to the low heat capacity of the air, the gas temperature in the chamber is equal to the temperature in the room, which is measured with a thermometer (Traceable, Fisher Scientific).

SUPPLEMENTARY MATERIAL 2 – DETERMINATION OF THE LOWER BOUND OF THE FLOW RATE IN THE ENVIRONMENTAL CHAMBER.

The supplied nitrogen leaves the environmental chamber (Figure 2.C.) through the outlet port directly into the atmosphere. Therefore, the possibility of counter diffusion of air from the atmosphere back into the environmental chamber was a concern. To diminish this counter diffusion, one has to ensure that the flow of gas leaving the chamber through the outlet port via advection is significantly greater than its flow due to molecular diffusion. The outlet diameter d_{out} sets a characteristic scale for this transport problem: one can estimate whether advection prevails over molecular diffusion in an imaginary hemisphere of diameter d_{out} adjacent to the outlet by calculating the Peclet number $Pe = U \cdot d_{out}/D$, where U is the mean flow velocity of nitrogen and D is the diffusion coefficient of the air or water molecules in nitrogen. The diffusion coefficients of the most important air components in nitrogen at 25°C are known¹: the water vapor - $D=0.21 \cdot 10^{-4} \text{ m}^2/\text{s}$; carbon dioxide (CO_2) – $D=0.14 \cdot 10^{-4} \text{ m}^2/\text{s}$, nitrogen oxide (NO) $D=0.18 \cdot 10^{-4} \text{ m}^2/\text{s}$. Thus, these individual gas components of air have roughly the same diffusion coefficient in nitrogen. We take $D=0.2 \cdot 10^{-4} \text{ m}^2/\text{s}$ for the estimates of Peclet number. The mean velocity is calculated through the given flowrate Q as $U = 4Q/(\pi d_{out}^2)$. With the flowrate $Q = 1$ Standard Cubic Foot per Hour ($1 \text{ SCFH} = 7.8 \cdot 10^{-6} \text{ m}^3/\text{s}$), the Peclet number is roughly $Pe = 2.5 \cdot 10^2$, suggesting that convective diffusion of the water vapor prevails over its molecular diffusion in the chamber. Therefore, at the nitrogen flow rates above 1 SCFH, the air outside the chamber should not drastically change the partial vapor pressure in the chamber; one expects that the humidity measured in the supply system is about the same as that measured in the chamber.

To verify this statement, a secondary humidity sensor (HIH-4030, Sparkfun) was temporarily placed directly inside the outer environmental chamber (Figure 2.C), nitrogen of various humidities and flow rates was passed through the system, and the readings from both sensors were compared (Figure S.1. Figure S.1). In the first experiment, a range of humidities was supplied at two flow rates: 1 SCFH and 0.5 SCFH ($7.8 \cdot 10^{-6} \frac{\text{m}^3}{\text{s}}$ and $3.9 \cdot 10^{-6} \text{ m}^3/\text{s}$, respectively). The humidity measured by the sensor embedded in the system was plotted against the humidity measured directly in the chamber for both cases (Figure S.2.A) The black line represents a perfect correlation in humidities between the two locations. The blue and red points show the actual measurements and demonstrate the discrepancy in the humidities between the two locations. At the higher flow rate, the discrepancy is contained under 5% in the low humidity limit, while at low flow rate, the discrepancy reaches up to 15%. Thus, the for the

uncertainty of the humidity measurement to be contained within 5%, the flow rate of at least 1 SCFH ($7.8 \cdot 10^{-6} \frac{m^3}{s}$) must be used.

In the second experiment, nitrogen of 0% humidity was supplied to the system at different flow rates. The measured values from both sensors are plotted against the flow rate in Figure S.2.B. In an ideal situations, both sensors should measure 0%. Due to counter diffusion, however, the discrepancy between the sensors increases as flow rate is decreased. The discrepancy at 1 SCFH ($7.8 \cdot 10^{-6} \frac{m^3}{s}$) flow rate is roughly 5%, which is consistent with the estimations and the first experiment. We thus confirm the lower bound for the supplied gas flow rate to be 1 SCFH ($7.8 \cdot 10^{-6} \frac{m^3}{s}$).

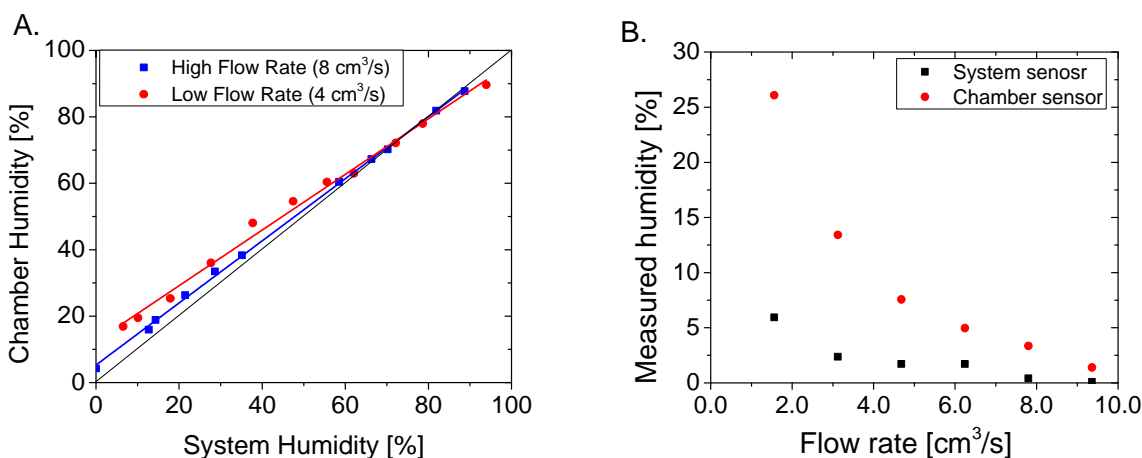


Figure S.2. A. Calibration of the humidity in the environmental chamber with the system humidity. The high flow rate data correspond to the Peclet number of about 250, and the low flow rate data correspond to the Peclet number of about 125. B. Dependence of the water vapor content in the supplied system and in the chamber on the flow rate. The measurements were taken after the system had reached equilibrium and the values no longer changed.

References

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