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Temporal Hygrometer Characterization: Design and First Test of a New, Metrological-Dynamic-Testing-Infrastructure

Felix Witt[1]*, Dominik Bergmann*[2]*, Florian Bubser*[1]*, Volker Ebert*[1]
[1] *Physikalisch- Technische Bundesanstalt, Bundesallee 100, 38116 Brunswick, Germany,*
[2] *Institut für Flugführung der Technischen Universität Braunschweig, Hermann-Blenk-Str. 27, 38108 Brunswick, Germany*
Corresponding Author volker.ebert@ptb.de

Summary:

A new, metrological-dynamic-testing-infrastructure (MetDynTI) for hygrometers is presented, comprising a flow test section driven by a switching water vapor (H_2O) step change generator, capable of fast, well defined, H_2O steps from 300 to up to 15000 µmol/mol. The step response of the test section is detected in real-time by means of an integrated, fast, direct tunable diode laser absorption spectroscopy (dTDLAS) hygrometer. The exact knowledge of the dynamic behavior of the driving section enables the dynamic characterization of subsequent test hygrometers exposed to the H_2O step change.

Keywords: Dynamic Characterization, Hygrometer, Laser Spectroscopy, dTDLAS, Metrology

Introduction

Water vapor (H_2O) in air is an essential parameter that is monitored in many home or workplace applications e.g. air conditioning or ventilation and is also key for industrial process control systems [1], or for weather forecast or for climate studies. Accurate monitoring of dynamic H_2O concentration [H_2O] changes which may be caused by opening a window or changing process parameters is key for process control systems and poses a significant challenge for most hygrometers used commonly [2]. Hygrometers are almost exclusively calibrated under quasi-static conditions. An accurate or even traceable characterization of their dynamic response, however, is often lacking, or needs to be strongly improved. Inaccurate dynamic coefficients often cause temperature oscillations. These may lead to discomfort or energy losses in a home setting or can have significant implications for an industrial process control system. One reason for this deficiency is the lack of a (metrologically) standardized dynamic hygrometer characterization. Here, we present a newly designed dynamic hygrometer test setup comprising: A) Generation of fast, defined [H_2O] step changes in air. B) A fast, absolute and sampling-free, optical reference [H_2O] analyzer. C) A gas flow test section in which the device under test (DUT) can be inserted and which is optimized to "maintain" the steep H_2O gradients. By comparison of traceable, H_2O step changes with the DUT dynamic behavior we can extract the DUTs dynamic characteristics and their dependence on step height, step direction, flow speed etc.

H_2O Step Generation and Flow Conditioning

Fig. 1 schematically shows the H_2O step generation, flow conditioning and optical measurement section (similar to [3]). A base flow of dry air ([H_2O] < 20 ppm), at ambient pressure, is dynamically mixed with humid air from one of the two thermodynamic static humidity generators. Two 3/2 valves enable fast switching between the generators without interrupting their flow. The upper and lower H_2O values can be adjusted between 300 and 15000 µmol/mol (= ppm). The air is injected into the measurement section (80 mm diameter) and homogenized using a sintered glass filter. A honeycomb flow rectifier is used to reduce the flow turbulences. The axial gas velocity inside the flow tube ranges from 0.06 to 0.33 m/s (20 to 100 l/min). The generated gas travels axially along a two-meter-long open pipe to prevent ambient effects on the measurement zone.

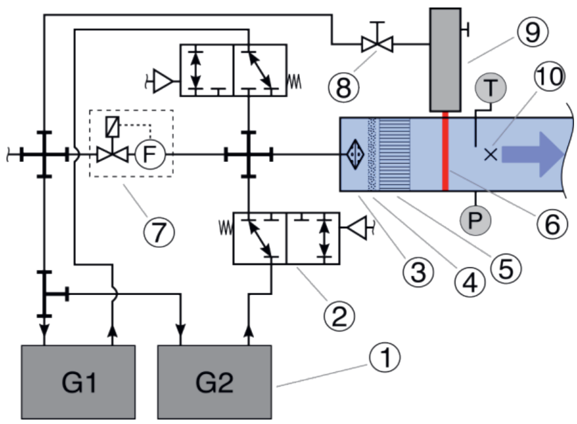

Fig. 1. Schematic test setup. 1: Humidity generators, 2: 3/2 valves, 3: Injection nozzle, 4: Sintered filter,

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5: Honeycomb flow rectifier, 6: dTDLAS laser measuring plane, 7: Flow controller, 8: Needle valve, 9 dTDLAS optic unit, 10: DUT Position

dTDLAS as a fast, reference Hygrometer

An optical multipath ring cell (#6 in Fig. 1), forming a thin, planar laser sheet, perpendicular to the flow, is used to analyze the generated [H_2O] step changes in front of the DUT via high-speed, sampling-free and SI-traceable, direct tunable diode laser absorption spectroscopy (dTDLAS) [4]. From the cell's spectral transmission dTDLAS derives calibration-free absolute H_2O concentration using a 1st-principles model based on the Lambert-Beer law, high accuracy H_2O spectral data as well as measured path length and gas temperatures/pressures [4]. The current setup uses an H_2O absorption line at 1370 nm. Measurements from 50 to 30000 ppm with a resolution of 1 ppm are feasible. The current max. time resolution lies near 14 Hz and will be improved further by a faster data acquisition. Fig. 2 shows a typical H_2O absorption profile with a fitted Voigt line shape indicating 315 ppm H_2O at 1013 hPa.

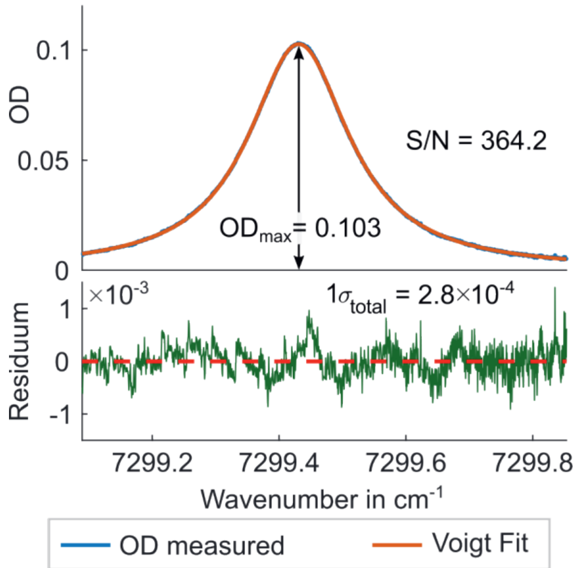

Fig. 2. Measured and fitted optical density (OD) of a single scan of the absorption line. Below: the residual be-tween fitted and measured data. The signal to noise ratio (S/N) defined by OD_{max} / $1\sigma_{total}$ is 364.

Results

Fig. 3 shows the dynamic [H_2O] at the optical cell measured with the dTDLAS-Hygrometer for a step from 315 ppm to 3731 ppm. At a total flow rate of 20 l/min it takes about 0.6 s for the changed concentration to reach the measurement plane of the laser and an additional 0.4 s to reach 10 % of the "final" step concentration. At t_{10} the local [H_2O] temporal "gradient" exceeds 3050 ppm/s, which is not achievable with most other hygrometers. t_{90} is reached 3.1 s after the [H_2O] change arrived at the laser. After t_{10}, i.e. after the early transition phase between t_{dead} and t_{10}, the [H_2O] dynamics is well described with a first order low pass. This well predictable behavior in combination with planned improvements to further reduce the step time will make it possible to mathematically remove the "influence" of the setup and to isolate the dynamic response behavior of a potential DUT in the test section.

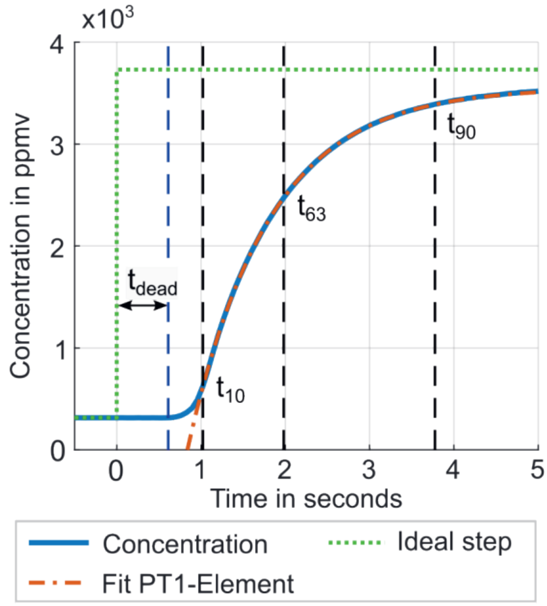

Fig. 3. [H_2O] step from 315 to 3731 ppm measured with the dTDLAS-Hygrometer. The new gas mix arrives at the measurement plane after a transport time of 0.6 s after the valves were actuated. An ideal low pass behavior (PT1-Element) is fitted to the step response between t_{10} and t_{90}. The fits coefficient of determination (R^2) is 1.000 the RMSE is 3.796. The "$t_{10} \rightarrow t_{90}$ response time" is 2.7 s.

References

[1] S. Bell, R. Benyon, N. Böse, et al., A Roadmap for Humidity and Moisture Measurement, Int J Thermophys 29, 1537–1543 (2008); doi: 10.1007/s10765-008-0419-8

[2] B. Buchholz, A. Afchine, A. Klein, et al., HAI, a new airborne, absolute, twin dual-channel, multi-phase TDLAS-hygrometer background, design, setup, and first flight data, Atmospheric Measurement Techniques 10, 35–57 (2017); doi: 10.5194/amt-10-35-2017

[3] E. Georgin, F. Bubser, R. Deschermeier, V. Ebert, Metrology of Transient Humidity Measurements: Dynamic Generation and Measurement of Humidity, Conference: TEMPMEKO 2019, Chengdu, China

[4] B. Buchholz, N. Böse, V. Ebert, Absolute validation of a diode laser hygrometer via intercomparison with the German national primary water vapor standard, Appl. Phys. B 116, 883–899 (2014), doi: 10.1007/s00340-014-5775-4