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Design and validation of a new primary standard for calibration of the top-end humidity sensors

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Abstract

The article discusses the design and results of the initial testing of a primary single pressure dew-point generator, which is used for calibration of the top-end dew-point sensors and other types of humidity sensors. The dew-point generator operates in the dew/frost-point range from −60 °C up to +80 °C. The first experiments indicate that the expanded uncertainty of the generated dew/frost point is in the order of ±0.03 °C. Two saturators were designed and implemented in a single compact system. As the size of the saturators is quite large and the requirements to temperature gradients and stability of the saturators strict, special liquid baths were designed, which assures uncertainty due to temperature stability and uniformity below 2 mK. The dew-point generator was constructed to either work in single pass, partially recirculation or complete recirculation mode. This provides flexibility both when using the generator for calibration work but also when using the generator for experiments i.e. when evaluating the efficiency of the saturators. In order to achieve leak tight recirculation a new magnetically coupled pump has been developed. In this article, special attention is concentrated on the design of the saturators, the thermostats, and the pump.

Keywords: Dew-point generator; Magnetically coupled pump; Single pressure generator; Liquid bath

1. Introduction

Until now, our reference standard for humidity consisted of a commercially available two-pressure dew-point generator operating in a dew/frost-point range from −35 °C up to +70 °C. Calibrations were made by comparison with an externally calibrated chilled mirror hygrometer purely using the generator as a humidity source. The set-up is quite similar to what is described in [1]. The expanded uncertainty achieved with the set-up is 0.12 °C. To be able to extend the range as well as improving the uncertainty more options were studied. Upgrading the existing facilities by further characterising, the two-pressure generator was considered. Others [2–4] have already successfully made such a step, but only minor improvements to the uncertainty could be expected and the range would remain the same (as

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also concluded in [1]). It was therefore decided to construct a primary dew-point generator aiming at the dew/frost-point range from −60 °C up to +80 °C due to our future calibration needs.

Humidity generators with different basic operating principles have been constructed and described by other laboratories [5–10]. So far, generators working according to either the two pressures (2-P) or single pressure (1-P) principle [5–9] obtained the best results reported. For both types of generators, the saturator efficiency is a key-factor. In the 1-P generators, the achieved uncertainty is furthermore limited by the performance of the thermostats containing the saturators and the uncertainty of the temperature measurement, whereas the uncertainty of the 2-P generators furthermore depends on the uncertainty of the pressure measurements and that of the used water vapour pressure equations (together with the equations for enhancement factor). The uncertainty of the vapour pressure equations may become significant when all other uncertainty sources have been minimised, especially in a low frost-point region. Theoretically, the single pressure principle therefore promises better uncertainty. On the other hand, 2-P generators in general offer faster response, which is advantageous when using it for calibrations. These considerations together with the considerable experience of the laboratory in temperature measurement led to the choice of constructing a generator according to the single pressure principle. The 1-P generators already constructed by other laboratories work as either single pass, partially recirculation or complete recirculation generators. To study the differences between the principles and for evaluating the saturators' efficiency, a generator that allowed the use of all techniques was designed.

2. The design of the generator

In a 1-P generator, sample carrier gas (typically dry nitrogen or air) passes through a saturator, to be saturated with water vapour at a fixed temperature (T_s) and pressure (P_s). Gas is then led at the same pressure to the output of the generator, where the unit under test (UUT) is connected. The dew point T_d at the output of the generator (1), depends on the temperature of the saturator T_s, the pressure inside the saturator P_s and the pressure at the input of the UUT, P_{UUT}, provided, that the saturation is complete and there is no water vapour loss between the saturator and the UUT (conservation of mass)

$$e_s(T_d) = \frac{e_s(T_s) \cdot f(P_s, T_s)}{f(P_{UUT}, T_d)} \cdot \frac{P_{UUT}}{P_s} \quad (1)$$

e_s and f denote water vapour saturation pressure formulae and enhancement factor formulae, respectively i.e. [11]. For single pressure generators where both pressures P_s and P_{UUT} ideally are the same, T_d equals T_s.

$$P_{UUT} = P_s \Rightarrow T_d = T_s \quad (2)$$

Since P_s and P_{UUT} are not exactly equal, which occurs due to some pressure drops over the sampling line in the generator or over the UUT, a small correction is applied to (1), as described in [12]. Thus, to determine the actual dew-point temperature, accurate measurements of T_s and pressure differences have to be carried out under the condition that the saturation of the gas is complete and no vapour has been lost between the saturator and the output of the generator. In this respect, the 1-P and 2-P generation methods are the same from theoretical point of view; but the pressure drop is so small in 1-P system that we can approximate: $T_d \approx T_s + \delta T_d$ (P_s,P_{UUT},T_s).

2.1. The saturators

The generator is intended to generate gas with a well-defined dew point in the range from −60 °C to +80 °C. To cover this range, two different saturators together with two different liquid baths were designed, an alcohol bath for the low temperature (LT) range and a water bath for temperatures above 20 °C – the high temperature (HT) range. Both of the saturators are similar in design (see Fig. 1). However, the HT saturator is larger in order to obtain a longer saturation path, which is needed for higher temperatures. Moreover, the HT saturator has special hole in the centre (see Fig. 1B) in order to keep the effect due to latent heat of vaporisation small. Namely, the larger the difference between the inlet and the outlet dew point of the gas is, more water needs to evaporate in saturator, causing the temperature of the gas to decrease slightly. To keep this effect small, the saturator dimensions are relatively large. In addition, heat exchange between the last part of saturation path and the bath liquid is increased by allowing bath liquid to flow through the centre of saturator. This hole enables also smaller temperature gradients across the saturator.

To ensure that the gas and saturator are in thermal equilibrium, the gas is thermally conditioned by