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CHARACTERIZATION OF LPM'S 1-T DEW POINT GENERATOR

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Abstract: This paper describes characterization of 1-T dew point generator developed at Laboratory for Process Measurement (LPM) self-. Present operating range of generator is from -7°C to 18°C dew point range. The air flows through saturator in closed loop and is controlled with regulated flow meters. Air saturation degree is determined by measuring the temperature deviations between saturator air outlet and liquid in saturator. Thermometers are connected to the resistance bridge, which is in turn connected to the computer for data acquisition. The main design features of the 1-T generator are presented. The deviations between generated dew point temperature and LPM's dew point transfer standard hygrometer (recently calibrated in PTB) are discussed. The deviations between saturator air outlet and liquid in saturator are also examined. The test results are presented in graphical and tabular form together with an example of uncertainty estimates for various test dew points.

Keywords: characterization, temperature deviations, measurement uncertainty

1. INTRODUCTION

The LPM's primary 2-T humidity generator is modified to operate as a 1-T dew point generator in view of pending interlaboratory comparison (EUROMET P621). Because of that, some of the features are being re-examined and tested in order to determine their influence on measurement uncertainty estimation. Recently calibrated LPM's dew point transfer standard, which also serves as a control unit in dew point generator, is now tested with LPM 1-T dew point generator in order to examine the deviations and compare those deviations with external calibration results. Furthermore, the temperature deviations between saturator air outlet and liquid in saturator (temperature of the thermostatic bath), which determine air saturation degree, are subject to measurement uncertainty estimation. Therefore, the testing is carried out to examine the behavior of deviation on various test dew point temperatures by using calibrated standard PRT's. Because of that, measurement uncertainty estimations are being re-examined.

2. THE GENERATOR

Fig. 1 shows a schematic diagram of the LPM's 1-T dew point generator [1]. The basic design features of 1-T dew point generator are as follows. The heat exchanger and the saturator are placed (immersed) in the isothermal bath set to the desired temperature and regulated by the external control unit. External control unit also controls cooling/heating of the thermostatic bath.

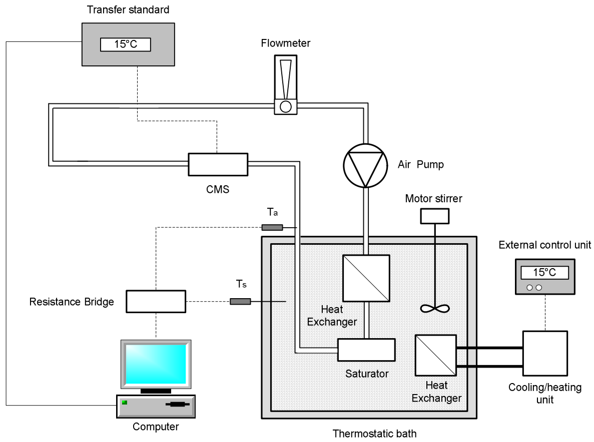

Fig. 1. 1-T dew point generator

The main generator parts are: the air pump, the saturation system with heat exchanger, the transfer standard with chilled mirror sensor (CMS) and the flow meter with a valve regulator. In parallel with the transfer standard it is possible to test another dew point hygrometer (device under test-DUT). The connection between generator parts is done with pipes of 17 mm internal diameter. This will allows for lesser pressure drop which is directly related to the dew point temperature [2].

All parts of the generator are made of stainless steel (pipes and thermostatic bath). The pipes are additionally insulated for the work in the frost point range.

The hart of the generator represents the heat exchanger coil and the saturator assembly. The saturator pipe is formed into the three dimensional shape (Fig. 2). Pipe is made of copper with internal cross-section of 17 mm and length of 1,2 m. It is half filled with distilled water. The degree of air saturation is determined with difference between outlet temperature of the air, T_a, and the bath fluid temperature T_s (Fig. 1). The outlet air temperature can determine the degree of saturation only if the air flow is at the bath (saturation) fluid temperature before entering the saturator pipe. Therefore the length of the heat exchanger coil has been calculated to worst-case heat exchange conditions regarding the desired range of the generator.

The heat exchanger is in spirally formed shape with the 102 mm average diameter of coil. Pipe of the heat exchanger is made from stainless steel with 12 mm cross-section and with total length of 2 m.

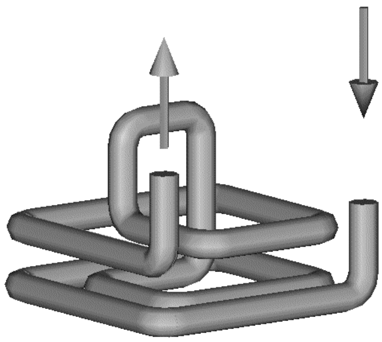

Fig. 2. The saturator

The generator is designed to operate in dew point range from -20°C to 60°C, but at the present it is operating in the reduced range from -7°C to 18°C. The upper limit of dew point range is limited by ambient temperature. In the future development of the generator the pipes will be additionally heated for higher dew point temperatures (above the ambient temperature).

Transfer standard (CMS) normally serves as a control unit of generated dew point temperature (General Eastern's M2/D2 combination).

PRT's that measure both key temperatures (T_a and T_s) are connected through the resistance bridge (Ametek's DTI 1000) with serial connection to the computer and monitored with LabView® based application.

3. GENERATION OF DEW POINT TEMPERATURE

The air is passing through saturator where the temperature and vapor pressure are reaching equilibrium with a plane surface of water (or ice) at fixed temperature t_s (the saturator temperature) and pressure P_s (the saturator pressure). The vapor mole fraction x_s is given by:

$$x_s = \frac{f_s \cdot e_s}{P_s} \qquad (1)$$

where f_s is the enhancement factor evaluated at the saturation temperature t_s and pressure P_s,
e_s is the saturation vapor pressure,
P_s is the saturation pressure.

One of the frequently used formulations for saturation water vapor pressure in air over water (or ice) is the one given by Sonntag (1994.) [3]:

$$e(t_s) = \exp\left(a_1 \cdot T_s^{-1} + a_2 + a_3 \cdot T_s + a_4 \cdot T_s^{2} + a_5 \cdot \ln T_s\right) \qquad (2)$$

Coefficients a_1 to a_5 representing numbers different for water and for ice with some associated uncertainty.

The generation of the dew point temperature is tested and observed through the deviations of saturator and outlet temperatures. Comparison between generator and transfer standard dew point hygrometer is also examined.

3.1. Saturator efficiency

Saturator efficiency (or the degree of saturation) represents the deviations between saturator and outlet temperature. The principle of operation of the generator lies on the basic assumption that the saturation of the carrier gas (air in this case) is reached after several passes over water (or ice) surface.

The air is forced to flow with the certain rate *m* over water (or ice) surface for a given length of saturator. Through each surface element at the boundary layer, evaporation or condensation with mass flow could be observed. Mass transfer is happening due to diffusion inside the boundary layer. At the equilibrium, when water vapor flow rate is equal to zero, the humidity content at the outlet will be equal to that at the inlet. Further, with the recirculating flow in steady conditions, the temperature is evenly distributed inside the air and water and its value is equal to the bath temperature. On the other, in case of non-equilibrium condition:

- an evaporating water vapor flow rate through the surface corresponds to an increase in the humidity content and dew point temperature (higher at the outlet than at the inlet of the saturator),
- a condensing water vapor flow rate through the surface corresponds to a decrease in the humidity content and dew point temperature (lower at the outlet than at the inlet of the saturator)

For a recirculating flow generator, this will happen during a temperature set point change. After few passes all the air is brought in contact with water surface and this will result in equilibrium condition.

There are many factors that can affect the degree of saturation:

- contamination of air or water which would result in a lower vapor pressure (lower dew point temperature),
- pressure gradients within the saturator which move the saturated air closer to exit (water must evaporate),
- temperature gradients within the saturator (in the thermostatic bath) which may move the air into and out of saturated state,
- flow rate variation
- air viscosity
- saturator pressure

Because of the temperature gradients in the bath, pressure drop in the saturator and limited time of measurement, the air will never be fully saturated. That is the reason why the thermometers (T_a and T_s) will never show the same temperature. At some level the air can be considered saturated to satisfactory extent and the residual temperature difference is earmarked for uncertainty consideration.

In order to validate the generator a set of series measurement has been carried out. For each temperature, in the range from 0°C to 18°C, in 2°C steps, a 40 measurement points are recorded. Care was taken that, after any new set temperature, the system reached a new equilibrium (stationary conditions) before recording the measurement. The set flow is adjusted to 6 l/min through the saturator. Before the measurement was taken both of the PRT's were calibrated against LPM's temperature working standards. In order to examine self heating of the thermometers LPM's precision thermometry bridge (ASL F700) was used and additional corrections were made.

The difference between saturator temperature and outlet temperature measured with PRT's T_a and T_s are shown in Fig. 3.

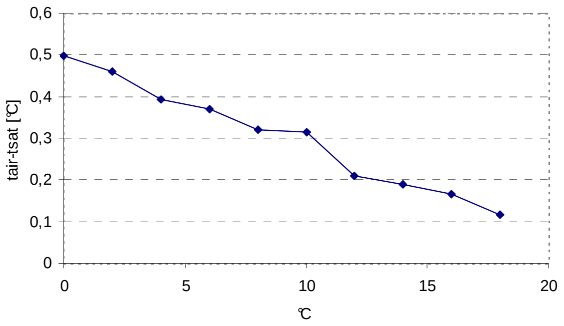

Fig. 3. Difference between saturator and outlet temperature

The experimental results show a significant difference in the lower dew point range and continuously reducing to higher dew point temperatures. The saturator efficiency (degree of saturation) can be defined and calculated as the ratio of actual vapor pressure at the saturator exit to the ideal vapor pressure calculated at saturator temperature [3]. For the given results this calculations shows, that at recirculating flow of 6 l/min, a degree of saturation at 0°C is 96,55 % and at 18°C is 99,27 %.

3.2. Comparison with transfer standard hygrometer

At the same time with temperature reading from PRT's, the reading from the transfer standard (CMS), which is connected in the recirculation loop, is recorded. General Eastern's D2 chilled mirror sensor is equipped with PRT which was not directly calibrated for this purpose, but the whole instrument (indicator unit M2 together with the sensor D2) was recently calibrated at PTB, Germany. The sampling flow rate through the chilled mirror sensor is set to 1 l/min.

The results of the comparison are shown in Fig. 4, where the differences between the generator temperature and the transfer standard dew point temperature, expressed in °C, are plotted.

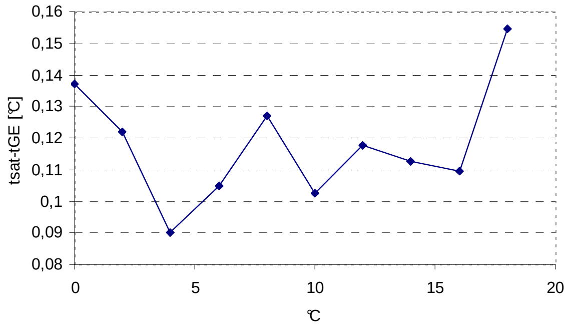

Fig. 4. Difference between saturator temperature and transfer standard read dew point temperature

The overall performance of the LPM's 1-T generator was tested by comparison against transfer standard. The results of comparison are shown in Fig. 5, where the differences between the generator temperature and the transfer standard dew point temperature are plotted. The measurement at each point, were repeated 40 times and the standard deviation calculated. The error bars represent the expanded uncertainty of the measurement (k=2 equals probability of 95 %). This measurement uncertainty includes combined standard uncertainty of the LPM's 1-T generator. This is evaluated in the following section 4.

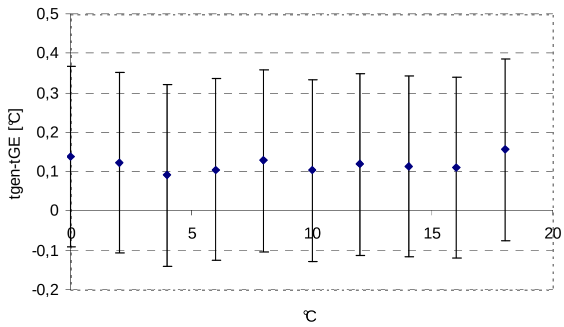

Fig. 4. Results of comparison of the LPM's 1-T dew point generator with transfer standard dew point hygrometer

Deviation of the transfer standard hygrometer through the range from -25°C to 45°C does not exceeds -0,1°C limit comparing to PTB precision generator and with that shows a good agreement with generated dew point temperature in the LPM's 1-T generator.

4. ESTIMATION OF THE UNCERTAINTY

The characterization of LPM's dew point generator includes the estimation of its overall uncertainty. In this way the main contributions are identified and the weakest links possibly improved. During these tests series, the pressure has not been measured, therefore the pressure components are not listed in the presented (Table 1. and Table 2.) uncertainty estimations for the two test points.

Table 1. Uncertainty estimation for the dew point temperature at 0°C

Quantity	Symbol	Value	Stand. Uncertainty	Probability	Sensitivity coeff.	Contribution [℃]
Saturation temp.	**t_d=t_s**	**0,014 ℃**				
Stab. of the measured temp.	$u(t_{s\ stab})$	0 ℃	0,001	rectangular	1	0,001
Saturator "efficiency"	$u(t_{s\ eff})$	0 ℃	0,1	normal	1	0,1
PRT Calibration	$u(t_{s\ PRT\ cal})$	0 ℃	0,04	normal	1	0,04
PRT long term stab.	$u(t_{s\ PRT\ stab})$	0 ℃	0,01	normal	1	0,01
PRT self heating	$u(t_{s\ PRT\ self}$	0 ℃	0,02367	rectangular	1	0,02367
PRT resolution (ind. unit)	$u(t_{s\ PRT\ res})$	0 ℃	0,02	rectangular	1	0,02
Saturator homogeneity	$u(t_{s\ sat\ hom})$	0 ℃	0,01	normal	1	0,01
Saturator temp. stab.	$u(t_{s\ sat\ stab})$	0 ℃	0,00866	normal	1	0,00866
Saturator water contamination	$u(t_{s\ water})$	0 ℃	0,001	normal	1	0,001
Dew point hygrometer	**t_{GE}**	**0,123 ℃**				
Stab. of the measured dew point temp.	$u(p_{stab})$	0 ℃	0,004	normal	1	0,004
Dew point hygrometer calibration	$u(p_{cal})$	0 ℃	0,025	normal	1	0,025
						0,116096
Expanded uncertainty (k=2)					**U=**	**0,232192**

Table 2. Uncertainty estimation for the dew point temperature at 18°C

Quantity	Symbol	Value	Stand. Uncertainty	Probability	Sensitivity coeff.	Contribution [℃]
Saturation temp.	**t_d=t_s**	**17,909 ℃**				
Stab. of the measured temp.	$u(t_{s\ stab})$	0 ℃	0,00086	rectangular	1	0,00086
Saturator "efficiency"	$u(t_{s\ eff})$	0 ℃	0,1	normal	1	0,1
PRT Calibration	$u(t_{s\ PRT\ cal})$	0 ℃	0,04	normal	1	0,04
PRT long term stab.	$u(t_{s\ PRT\ stab})$	0 ℃	0,01	normal	1	0,01
PRT self heating	$u(t_{s\ PRT\ self}$	0 ℃	0,02367	rectangular	1	0,02367
PRT resolution (ind. unit)	$u(t_{s\ PRT\ res})$	0 ℃	0,02	rectangular	1	0,02
Saturator homogeneity	$u(t_{s\ sat\ hom})$	0 ℃	0,01	normal	1	0,01
Saturator temp. stab.	$u(t_{s\ sat\ stab})$	0 ℃	0,00173	normal	1	0,00173
Saturator water contamination	$u(t_{s\ water})$	0 ℃	0,001	normal	1	0,001
Dew point hygrometer	**t_{GE}**	**17,754 ℃**				
Stab. of the measured dew point temp.	$u(p_{stab})$	0 ℃	0,0032	normal	1	0,0032
Dew point hygrometer calibration	$u(p_{cal})$	0 ℃	0,025	normal	1	0,025
						0,11576
Expanded uncertainty (k=2)					**U=**	**0,23152**

5. CONCLUSION

In order to improve the characterization of LPM's 1-T dew point generator a further investigation has been carried out. General principles of design and main design features have been described and presented. The generator characteristics were further investigated in the matter of saturator efficiency (degree of saturation) and by comparison with the transfer standard chilled mirror sensor hygrometer. The generator was tested in the dew point range from 0°C to 18°C, in 2°C steps. The experimental results show differences between saturator and outlet temperature in the lower dew point range with decreasing trend with higher values of dew point temperature. The calculations from the obtained results showed that the degree of saturation is found to be in the range from 96,55 % at 0°C to 99,27 % at 18°C. This result pointed out that some further investigations in the technical part of the saturation system must be carried out.

The comparison of the generator with transfer standard hygrometer showed an agreement within the expanded uncertainty of around U=0,23°C (k=2), over the range from 0°C to 18°C. The results are presented in graphical and tabular form.

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