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REPORT

Uncertainty evaluation of the relative humidity facility at NPL

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ABSTRACT

A relative humidity calibration facility has been constructed and validated at the National Physical Laboratory. This facility uses the present NPL humidity generators to provide gas of a known dew point to one of two temperature-controlled chambers. In this way a known relative humidity is generated in the chamber. The instrument to be calibrated is placed in the temperature-controlled chamber. The range of temperatures available at present is from 1 °C to 80 °C with a range of relative humidity of 2 %rh to 98 %rh over most of the temperature range. The uncertainty with which this new facility will operate is in general better than 0.5 %rh. This project has been carried out as part of the DTI's National Measurement System Programme for Mass, 1996 to 1999, project 4, Humidity Standards.

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1 INTRODUCTION

The National Physical Laboratory (NPL) operates a range of humidity generators as part of the provision of the UK's National Measurement System. These humidity generators provide traceable measurements of dew point for UK industry, in particular for laboratories accredited by the United Kingdom Accreditation Service (UKAS) for calibration of humidity measuring devices and test chambers, and for national measurement institutes in other countries.

NPL presently operates two humidity generators which together cover the dew-point temperature range -75 °C to 82 °C. The High-range Dew-point Generator (HDG) operates over the range from -3 °C to 82 °C and is a recirculating generator. The Standard Humidity Generator (SHG) covers the range -75 °C to 82 °C, and can be used in both recirculating and single pass modes. A third humidity generator, dedicated to the range below 0 °C, is being developed.

Until now, traceable relative humidity (rh) measurements in the UK have not been provided at national standard level, but have been derived indirectly at secondary level laboratories from a dew-point measurement and a separate temperature measurement. Increasing pressure from UK industry initiated the development of an rh calibration facility that has direct traceability to the UK national dew point standard. This new standard utilises the already verified dew-point generators as a known and stable source of humid gas, and controls this humidified gas at a higher temperature to create a known rh.

This report describes the types of instrument to be calibrated, the equipment used in the operation of the standard, the operating principle and the determination of the components of the uncertainty of the new facility.

2 DEFINITIONS

Dew point: the temperature at which dew, or condensation, forms, on cooling a gas

Relative humidity: the ratio of the actual vapour pressure to the saturation vapour pressure over a plane liquid water surface at the same temperature, expressed as a percentage

Vapour pressure: or water vapour partial pressure is that part of the total pressure contributed by the water vapour

Enhancement factor: the correction to be applied to the vapour pressure to allow for the non-ideal behaviour of the gas

Psychrometer (or wet- and dry-bulb hygrometer): consists of two matched temperature sensors over which humid air is drawn. One sensor is enclosed in a porous medium (wick or wet sock) which is kept wet by capillary action from a reservoir of water

Electronic rh probe: generalised description of a type of sensor that uses the change in electrical property of a hygroscopic material to detect a change in relative humidity

prt: platinum resistance thermometer, based on the principle that the electrical resistance of an encapsulated platinum winding varies with change in temperature

3 OPERATING PRINCIPLES

The essential aspects of the new rh facility are the dew point generation and the rh chamber. The principle of operation of the dew-point generators is to saturate a gas (commonly air) with water vapour at a known temperature and pressure. If the temperature of the gas is then raised, the saturation temperature (dew point) and the actual water vapour pressure will remain constant but at the higher temperature the saturation water vapour pressure will be higher. The ratio of these two vapour pressures will give the relative humidity, usually expressed as a percentage. The new rh facility uses the existing dew-point generators to saturate gas at a controlled temperature and pressure. The gas is then directed into a chamber held at a higher controlled temperature. In this way a known rh is created.

A detailed evaluation of the NPL dew point generators has been undertaken and reported [1,2,3]. The dew point uncertainty is established and its effect on the rh uncertainty can be calculated. The remaining contribution to the overall rh uncertainty arises from issues related to the temperature of the rh chamber and the type of instrument being calibrated.

4 RELATIVE HUMIDITY HYGROMETERS

There are at present two types of rh instrument which are considered suitable for calibration to the very best uncertainty: psychrometers and electronic rh probes. Each operates in a very different manner and so requires different calibration conditions. As a result the NPL rh calibration facility incorporates two separate calibration chambers designed to meet the requirements of these two types of hygrometer.

4.1 Psychrometers

A psychrometer, or wet- and dry-bulb hygrometer, incorporates two temperature elements one of which is covered with a wetted sock. Air is drawn across the two elements by a fan. The temperature of the wet element is reduced by comparison to that of the dry element by a transfer of heat by evaporation to the surrounding medium from the wetted sock. When the rate of heat transfer from incoming air balances the loss of energy due to vaporisation, the temperature reading of the wet element will be steady. From the temperature difference between the wet and dry elements the relative humidity of the incoming air can be calculated

Although the principles involved in the operation of a psychrometer are fundamental and the predicted temperature difference between the wet and dry elements at a given rh can be calculated, there are many issues associated with the design and operation of a psychrometer that can dramatically affect the performance [5]. It is for these reasons that a calibration against a humidity standard is necessary

The repeatable operation of a psychrometer is dependent on a high and steady flow of air over the sensing elements, and the best psychrometers are equipped with a fan or impeller to maintain the necessary air flow - typically up to 3 m s^{-1}. In any calibration system it is essential to maintain the same conditions during calibration as during use, and the accepted practice in calibrating psychrometers is to place the device in a chamber through which gas at a controlled humidity flows at a rate similar to the flow-rate created by the psychrometer's own impeller. The impeller must be operating during the calibration, and the flow rate of the calibration system must be matched to that of the psychrometer to ensure that the impeller is neither under- nor over-loaded, since either condition would affect the local environment of the sensor elements.

For this reason it is necessary to have a calibration system which is capable of generating a high but variable flow rate. In a system whose calibration chamber has a diameter of 150_mm (the minimum practical dimension to contain a range of psychrometers) a flow rate of 3 m s^{-1} equates to around 700 litres per minute, so for calibration of psychrometers a chamber is placed in the re-circulation path of the NPL's High-range Dew-point Generator, which has been specially designed to operate at such high flow rates.

4.2 Electronic rh probes

This type of rh measuring instrument typically incorporates a film sensing element in which an electrical property (resistance, capacitance) varies repeatedly with change in humidity. Devices of this type always require calibration, since the principle of operation is not in any sense "fundamental". The high gas flow rate required for psychrometer calibration is not required for electronic devices, but they have other limitations, such as poor linearity, poor repeatability of measurement at maximum and minimum rh values (depending on the sensor type), a large temperature coefficient and the likelihood of permanent damage if subjected to condensation conditions (i.e. rh of 100 %). For the calibration of these devices a second calibration chamber has been developed, which can be used with either of the NPL's dew-point generators but is more often used with the Standard Humidity Generator. This low flow rate chamber is fitted with a variety of ports to house the many different shapes and sizes of probes which are fitted to electronic rh devices.

5 THE CALIBRATION SYSTEMS

The rh facility is divided into two regimes. For some types of instrument a high flow rate of gas is required for the instrument to operate but for others only a small flow rate is needed.

5.1 High flow rate system

This system consists of the calibration chamber and a temperature conditioning coil, immersed in a well-stirred temperature controlled bath identical to that used for the HDG. The psychrometer is placed into the chamber and the system is then connected into the re-circulation path of the HDG (see Figure 1). The conditioning coils bring the gas from the HDG saturator to the same temperature as the chamber. The conditioning coils consist of four tubes into which the gas from the HDG saturator is split. This gives an improved efficiency in heat transfer to the flowing gas due to the larger surface area and because at no time is the gas more than 12 mm from the tube wall. The velocity of the gas inside the conditioning coils and the chamber in most conditions is sufficiently high to produce a turbulent flow pattern. The turbulent flow increases the heat exchange efficiency by reducing the slow moving boundary layer near the tube wall and introducing heat energy flow by convection as well as by conduction.

The flow pattern inside the chamber has been measured with the chamber empty and with a dummy load the size of a typical instrument. Throughout the working volume of the chamber the velocity of the flow is approximately constant.

Location of the instrument under test in the re-circulation path of the HDG carries a risk of contamination of the saturation system of the HDG, so particular attention must be paid to cleaning the psychrometer before calibration, and to maintaining the cleanliness of the entire system. In use, the performance of the HDG is monitored using a dew-point hygrometer, and any contamination of the saturation system would be apparent from the behaviour of this monitoring instrument.

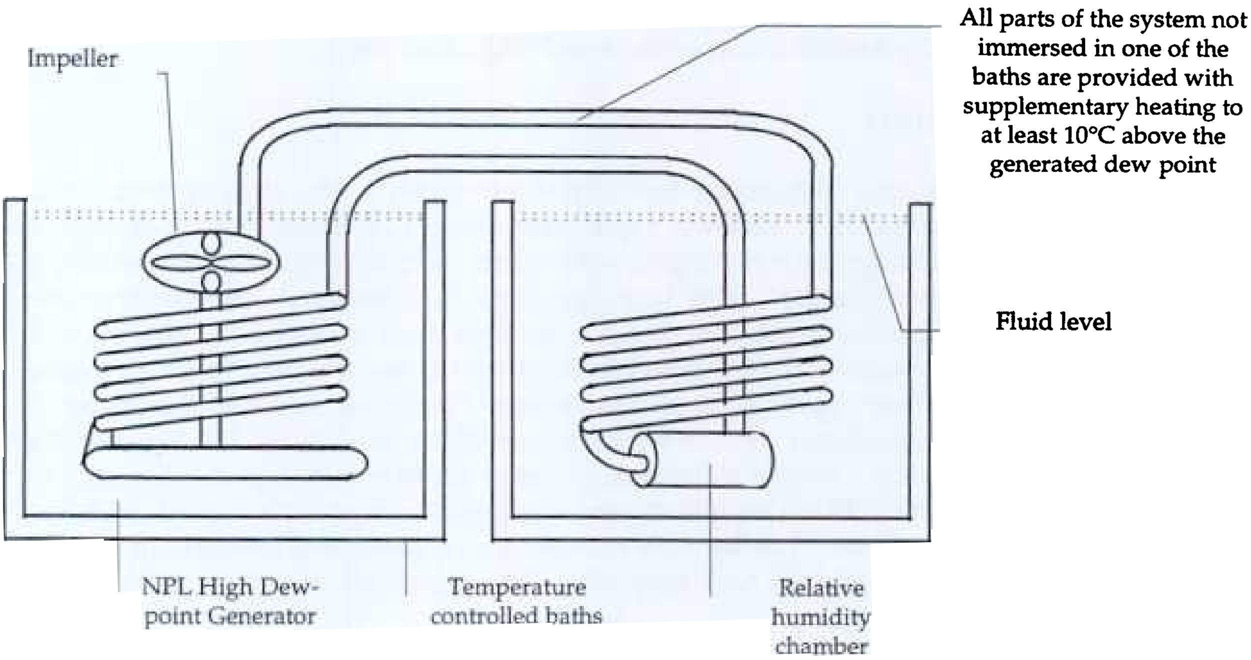

Figure 1 High flow rate system

5.2 Low flow rate system

This system also consists of a chamber and conditioning coil immersed in a well-stirred bath. The most significant difference in its mode of operation is that it is placed in the "bleed-off" path of the appropriate generator, rather than in the re-circulation path. The gas passing through the chamber is vented to the atmosphere via a needle-valve and flow controller. This has the advantage that the re-circulation system of the generator is protected from contamination. However the flow rate is limited to a maximum of 1 litre per minute.

This low flow rate chamber can be used with either the SHG or the HDG. It consists of a chamber of approximate volume 120 cm^3 . Around the chamber is a coil of pipe to temperature-condition the incoming gas. The chamber has two apertures to suit rh electronic probes of common sizes and two apertures for prts used to measure the air temperature. The chamber and conditioning coil are housed in a temperature-controlled, well stirred fluid bath with tubes leading from the apertures to above the surface of the fluid to prevent the test probes from getting wet. The unused apertures are sealed during operation of the system.

For ambient temperatures up to 20 °C the temperature conditioning of the laboratory is adequate to prevent thermal gradients along the test probes, but for elevated temperatures a temperature-controlled enclosure can be placed above the bath. This not only reduces thermal gradients in the test probe but also improves temperature gradients in the fluid bath.

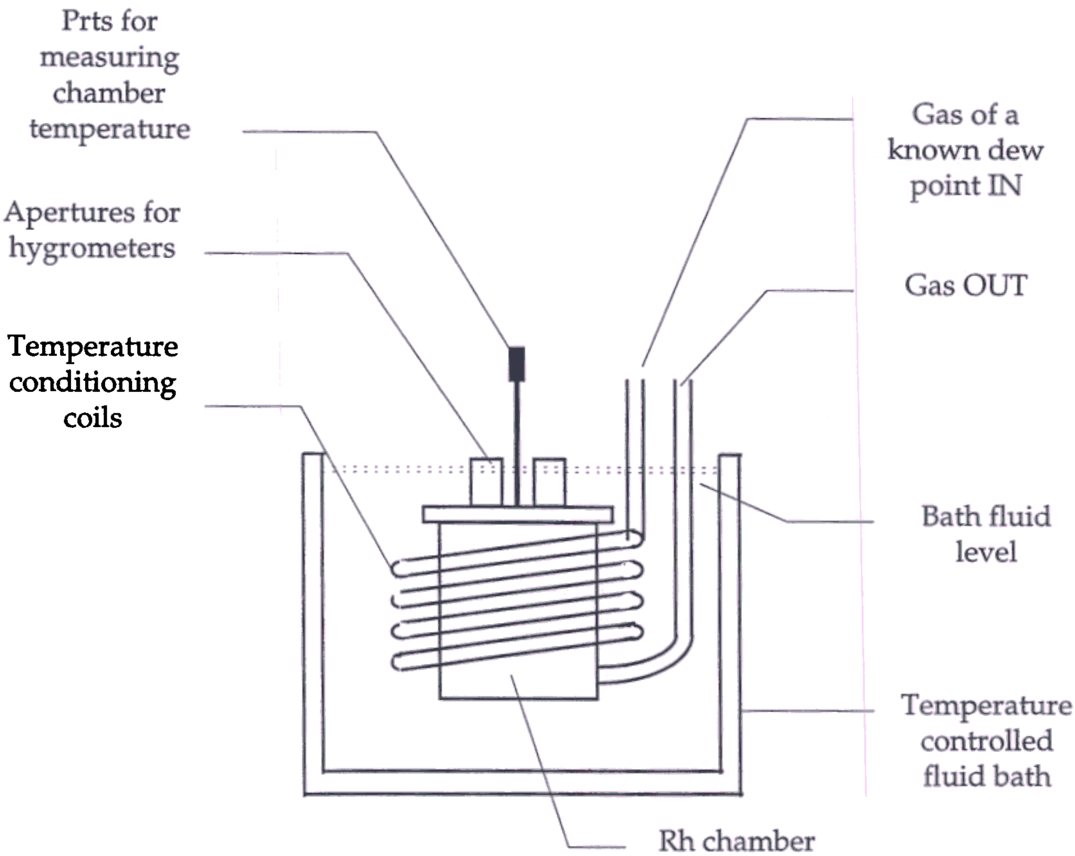

Figure 2 Low flow rate rh chamber

6 COMPONENTS OF UNCERTAINTY

In the operation of the relative humidity generator many components need to be considered in order to minimise the uncertainty in calibrating rh sensors. The individual contributions to the uncertainty have been combined to conform with the recommendations of the "Guide to the expression of uncertainty in measurement" prepared by the International Organization for standardization in 1993 [8] and the later revision of NAMAS document M3003 [9].

6.1 GENERATED DEW POINT

The uncertainty in the generated dew point has been evaluated for the dew-point standards at NPL [1,2,3]. The uncertainty in the generated dew point is between 0.03 °C and 0.05 °C in the dew point range from -50 °C to +82 °C.

6.2 TEMPERATURE MEASUREMENT

The temperature of the gas entering the rh chamber and that of the chamber itself will, along with the dew point and pressure, determine the relative humidity. The temperature inside the chamber is measured using prts which are calibrated annually by NPL's Temperature Section to ITS 90. The uncertainty in this calibration is 0.01 °C.

The resistance of a prt will slowly increase with time as the platinum ages. This drift can be monitored by regularly checking the value of the resistance at the triple point of water. The average annual value of drift measured in this way on several prts over a period of more than 5 years was found to be 0.01 °C.

In order to measure the resistance of a prt it is necessary to have an electric current flowing through it. The consequence of this is to cause the prt itself to heat up. This self-heating will depend on the type of prt, the current being used and the conditions that the prt is used in. The self-heating effect of the prt can be measured while in a stable condition by using different excitation currents and extrapolating the measured points to correspond to a zero current. From this the self-heating at the operating current can be determined in the conditions applied. The self-heating of the prt will change if used in liquids or gases or different flow conditions, and must therefore be determined for the conditions used.

A correction can be applied for the self-heating effect but a component of uncertainty must be applied for the uncertainty in the correction. The self-heating effect for the prts used was determined during their calibration at the triple point of water. The average value was found to be 0.002 °C. Determinations of the self-heating effect have been undertaken in the flow conditions inside the generators, these do not differ from the values obtained during calibration by more than the fluctuations of the system and therefore an estimated uncertainty of 0.002 °C in the self-heating determination is considered to be appropriate.

The thermal conduction along the prt sheath, often referred to as "stem conduction", is minimised in the high flow rate system by fully immersing the prt inside the chamber. In the low flow system that part of the prt that is not inside the chamber is either immersed in the temperature controlled bath fluid or in the air enclosed above the bath which is kept at the same temperature as the chamber. An uncertainty of 0.005 °C has been estimated to allow for any measurement error caused by this effect.

The resistance of the prts is measured using a 75 Hz ac resistance bridge. The resistance bridge compares the resistance of the prt with an internal standard resistor. The internal standard resistor of the bridge is annually compared with a pair of standard resistors which have nominal values of 25 Ω and 100 Ω. Both are calibrated at NPL. The uncertainty in the resistance measurement, the bridge drift, repeatability and resolution are assumed to be equivalent to 0.002 °C, 0.001 °C, 0.001 °C and 0.001 °C respectively. The uncertainty of the calibration of the standard resistors and their drift is the equivalent of less than 0.0001 °C and is therefore considered to be of no significance.

6.3 TEMPERATURE GRADIENTS

Any variation in the air temperature inside the chamber will locally change the generated rh. Therefore it is essential that any temperature differences are small and known. The temperature in the rh chamber is measured using two prts spaced either side of the test instrument. In this way any gradient across the instrument can be calculated and the effect minimised. The use of two prts also ensures that any malfunction or change in calibration of one of them can easily be detected.

The temperature variations in the bath fluids surrounding the rh chambers have been measured along with the temperature profiles within the chambers. The maximum temperature variation from one point to another in the working volumes of the test chambers was found in the high flow rate chamber, this variation of 0.064 °C is taken as the worst case and is applied to the overall uncertainty of the rh standard.

The uncertainty with which the temperature variations can be measured will depend on the stability of the system and the technique used. If several prts are spatially orientated around the measurement area, each prt will have its own associated temperature measurement uncertainty as discussed above in 6.2. To calculate the uncertainty in the measurement between two points, the uncertainties of each temperature measurement will have to be combined. However, for temperature difference measurements in a stable system, if the positions of two prts are exchanged for a second measurement certain contributions to the measurement uncertainty can be eliminated. An uncertainty of 0.01 °C has been estimated for the temperature variation measurement.

6.4 TEMPERATURE CONDITIONING

In the high flow rate chamber the temperature difference between the generated dew point and the rh chamber could be more than 50 °C. This causes a large heat flow to the gas as it passes from the dew point saturator to the rh chamber and in the reverse direction as it passes back into the dew point saturator.

The efficiency of the temperature conditioning itself does not directly contribute to the overall uncertainty but will contribute to the temperature differentials in the chamber. It is therefore necessary to have efficient temperature conditioning. The temperature conditioning in the HDG has been fully evaluated [3]. The temperature conditioning system in the rh chamber bath is identical to that used in the HDG and is assumed to be equally efficient.

The temperature conditioning in the low flow rate chamber covers the same temperature range as the high flow rate system but the quantity of gas to be conditioned is much less and so the length of conditioning coil is reduced accordingly.

6.5 PRESSURE

The pressure in the generator pipe work is controlled at just above atmospheric pressure at 105.0 kPa. This is to encourage the tendency for any leak to be outwards. An inwards leak would disturb the equilibrium of the system and could locally change the dew point of the circulating gas. If a leak inwards were between the dew point generator and the rh chamber the dew point of the gas entering the chamber could be altered. However if the leak were on the return path from the chamber to the dew point generator then the correct dew point would be established with the next pass through the saturator coil.

The important pressure measurements are those at the point of saturation and at the point of use as the dew point is dependent on the pressure. The pressure measurements are taken in the middle of the dew point saturator, at the saturator exit and in the rh chamber. The gradients are largest at high dew-point temperatures and a correction for this is applied to the generated dew point.

The measurements are made using an electrical strain-gauge type of transducer. The transducers are calibrated annually at NPL with traceability to the national standard for pressure. An uncertainty of 0.022 °C (equivalent to 100 Pa) due to the calibration, annual drift and temperature compensation is added to the overall uncertainty in the rh calibration system.

6.6 FLOW VARIATIONS

The flow through the high flow rate rh chamber is monitored by a flow meter at the inlet to the temperature conditioning coils before the chamber itself. The dew-point generator has its own flow measurement [4]. By having two flow measuring devices in the system the flow pattern around the system can be monitored more closely.

The flow in the low flow rh chamber is kept at between 0.5 and 1 litre per minute and is exhausted to atmosphere. The effect of this on the dew point generators is the same as attaching an extra dew-point hygrometer and has been accounted for in the uncertainty of the generator.

Problems have been encountered with some electronic rh probes that have a poor seal between the sensing element and the electronics in the handle. The leak rate through such instruments can be significant. This is most problematic when using the low flow rate rh chamber connected to the HDG, because the large diameter pipes of the HDG can deliver a high flow rate. In the presence of such a leak the draw off flow rate can be sufficiently large as to affect the saturation efficiency of the HDG. The problem has been controlled by enclosing the hygrometer handle in a thin polythene tube, one end of which is sealed around the chamber adapter and the other is either closed or sealed around the cable leading to the display unit. In this way the leak rate can be reduced to an acceptable level.

Leaks around the electrical cables leading to a psychrometer cause a similar problem. When the need arises the problem is overcome by the use of a split collet around the offending cable.

Variations in the recirculation flow rate within the operating range have little effect on the flow through the psychrometer. To test this a hot wire anemometer was placed inside the test psychrometer and the flow rate was measured. The same flow was recreated inside the generator (with the fan operating) with differing recirculation flow rates. This demonstrates that the careful design of the chamber has enabled the fan of the psychrometer to extract the required amount of gas from that supplied and the rest is diverted around the body of the psychrometer.

6.7 UNCERTAINTY IN THE CALCULATIONS

It is necessary to convert the generated dew point and chamber temperature to relative humidity, as described below.

6.7.1 Vapour pressure

Relative humidity is essentially the ratio of two vapour pressures which are calculated from values of dew point and temperature. Therefore any errors in vapour pressure calculations will be most noticeable when the difference between the two vapour pressures is greatest, at low values of rh.

The conversion from dew-point temperature to vapour pressure is achieved using established equations of which there are many. A recent survey of 90 equations was published by Gibbins [6]. The quoted uncertainty of these equations is small and the agreement with the very little experimental data is sufficient for this application. With so many equations to choose from it is essential to standardise the ones used. The equations widely adopted by national measurement institutions are those by Sonntag [7].

6.7.2 Enhancement factor

The enhancement factor is a correction applied to the calculation of vapour pressure, which allows for the non-ideality of the gas and the deviation from ideal behaviour of the solution. The correction varies a small amount with vapour pressure.

When calculating rh from a dew point and a temperature it is usually assumed that the enhancement factor will cancel out in the equation, the possible error will be largest at low rh where the ratio of vapour pressures and enhancement factor is greatest. The small uncertainty associated with the assumption is added to the overall uncertainty of the rh standard.

7 COMBINING THE UNCERTAINTIES

The individual components of uncertainty have been evaluated and combined by taking the square root of the sum of the squares of the individual standard uncertainties, in accordance with the "Guide to the expression of uncertainty in measurement"[8] and the UKAS document M3003[9]. The individual components of the overall uncertainty have been assessed separately and it is therefore assumed that they are un-correlated.

The components of uncertainty reported in sections 6.2 to 6.4 are those associated with the temperature in the test chamber. These are used to determine the combined uncertainty of temperature in the chamber.

The component uncertainties are detailed in Table 1 and summarised in Table 2.

Table 1
NPL Relative Humidity Calibration Facility
Contributions to uncertainty of measurement

	Standard uncertainty expressed in %rh arising from:													
	Uncertainty in generated dew point	Calibration of prt	Repeatability of prt	Drift of prt	Variability in prt drift	Hysteresis of prt	Stem conduction effect	Fluctuations in prt readings	Uncertainty in self heating measurement	Resistance bridge calibration	Resistance bridge repeatability	Resistance bridge resolution	Resistance bridge drift	Variability in resistance bridge drift
distribution	normal	normal	normal	rectangular	rectangular	rectangular	rectangular	rectangular	rectangular	normal	normal	rectangular	rectangular	normal
divisor	2	2	1	1.732	1.732	1.732	1.732	1.732	1.732	2	1	1.732	1.732	1
%rh	Ambient temperature 1 °C													
2	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.026	0.007	0.007	0.008	0.002	0.004	0.004	0.004	0.002	0.002	0.001	0.001	0.001	0.001
40	0.048	0.015	0.015	0.017	0.005	0.008	0.008	0.008	0.003	0.004	0.003	0.002	0.002	0.003
60	0.068	0.021	0.021	0.025	0.007	0.012	0.012	0.012	0.005	0.006	0.004	0.002	0.002	0.004
80	0.089	0.029	0.029	0.033	0.010	0.017	0.017	0.017	0.007	0.009	0.006	0.003	0.003	0.006
98	0.106	0.035	0.035	0.041	0.012	0.020	0.020	0.020	0.008	0.011	0.007	0.004	0.004	0.007
	Ambient temperature 20 °C													
2	0.003	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.012	0.003	0.003	0.004	0.001	0.002	0.002	0.002	0.001	0.002	0.001	0.000	0.000	0.001
40	0.042	0.012	0.012	0.014	0.004	0.007	0.007	0.007	0.003	0.004	0.002	0.001	0.001	0.002
60	0.059	0.019	0.019	0.021	0.006	0.011	0.011	0.011	0.004	0.006	0.004	0.002	0.002	0.004
80	0.077	0.025	0.025	0.029	0.009	0.014	0.014	0.014	0.006	0.009	0.005	0.003	0.003	0.005
98	0.092	0.030	0.030	0.035	0.011	0.018	0.018	0.018	0.007	0.011	0.006	0.004	0.004	0.006
	Ambient temperature 40 °C													
2	0.003	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.020	0.005	0.005	0.006	0.002	0.003	0.003	0.003	0.001	0.002	0.001	0.001	0.001	0.001
40	0.036	0.011	0.011	0.012	0.004	0.006	0.006	0.006	0.002	0.003	0.002	0.001	0.001	0.002
60	0.052	0.016	0.016	0.019	0.006	0.009	0.009	0.009	0.004	0.005	0.003	0.002	0.002	0.003
80	0.066	0.021	0.021	0.025	0.007	0.012	0.012	0.012	0.005	0.006	0.004	0.002	0.002	0.004
98	0.079	0.026	0.026	0.030	0.009	0.015	0.015	0.015	0.006	0.008	0.005	0.003	0.003	0.005
	Ambient temperature 60 °C													
2	0.002	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.017	0.005	0.005	0.005	0.002	0.003	0.003	0.003	0.001	0.001	0.001	0.001	0.001	0.001
40	0.032	0.009	0.009	0.011	0.003	0.005	0.005	0.005	0.002	0.003	0.002	0.001	0.001	0.002
60	0.045	0.014	0.014	0.016	0.005	0.008	0.008	0.008	0.003	0.004	0.003	0.002	0.002	0.003
80	0.057	0.019	0.019	0.021	0.006	0.011	0.011	0.011	0.004	0.006	0.004	0.002	0.002	0.004
98	0.068	0.023	0.023	0.026	0.008	0.013	0.013	0.013	0.005	0.007	0.005	0.003	0.003	0.005
	Ambient temperature 80 °C													
2	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.016	0.004	0.004	0.005	0.001	0.002	0.002	0.002	0.001	0.001	0.001	0.000	0.000	0.001
40	0.028	0.008	0.008	0.009	0.003	0.005	0.005	0.005	0.002	0.002	0.002	0.001	0.001	0.002
60	0.053	0.012	0.012	0.014	0.004	0.007	0.007	0.007	0.003	0.004	0.002	0.001	0.001	0.002
80	0.067	0.016	0.016	0.019	0.006	0.009	0.009	0.009	0.004	0.005	0.003	0.002	0.002	0.003
98	0.080	0.020	0.020	0.023	0.007	0.011	0.011	0.011	0.005	0.006	0.004	0.002	0.002	0.004

										Combined uncertainty	Expanded uncertainty
Effect of temperature conditioning	Temperature gradients in rh chamber	Uncertainty in gradient measurement	Effect of pressure gradients on generated dew point	Pressure effects in rh chamber	Flow rate measurement	Variability in flow rate	Effect of leaks	Vapour pressure calculations	Enhance factor calculations	k=1	k=2
rectangular	rectangular	rectangular	rectangular	rectangular	rectangular	rectangular	rectangular	rectangular	rectangular		
1.732	1.732	1.732	1.732	1.732	1.732	1.732	1.732	1.732	1.732	%rh	%rh
0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.007
0.002	0.053	0.008	0.002	0.002	0.002	0.002	0.002	0.008	0.004	0.062	0.123
0.003	0.107	0.017	0.003	0.003	0.003	0.003	0.003	0.017	0.008	0.123	0.246
0.005	0.158	0.025	0.005	0.005	0.005	0.005	0.005	0.025	0.012	0.180	0.361
0.007	0.213	0.033	0.007	0.007	0.007	0.007	0.007	0.033	0.017	0.242	0.485
0.008	0.261	0.041	0.008	0.008	0.008	0.008	0.008	0.041	0.020	0.296	0.591
0.000	0.005	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.006	0.011
0.001	0.023	0.004	0.001	0.001	0.001	0.001	0.001	0.004	0.002	0.027	0.054
0.003	0.091	0.014	0.003	0.003	0.003	0.003	0.003	0.014	0.007	0.105	0.210
0.004	0.137	0.021	0.004	0.004	0.004	0.004	0.004	0.021	0.011	0.156	0.313
0.006	0.183	0.029	0.006	0.006	0.006	0.006	0.006	0.029	0.014	0.208	0.417
0.007	0.224	0.035	0.007	0.007	0.007	0.007	0.007	0.035	0.018	0.254	0.508
0.000	0.004	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.005	0.010
0.001	0.040	0.006	0.001	0.001	0.001	0.001	0.001	0.006	0.003	0.047	0.093
0.002	0.079	0.012	0.002	0.002	0.002	0.002	0.002	0.012	0.006	0.091	0.181
0.004	0.118	0.019	0.004	0.004	0.004	0.004	0.004	0.019	0.009	0.135	0.271
0.005	0.157	0.025	0.005	0.005	0.005	0.005	0.005	0.025	0.012	0.179	0.358
0.006	0.193	0.030	0.006	0.006	0.006	0.006	0.006	0.030	0.015	0.219	0.437
0.000	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.004	0.009
0.001	0.034	0.005	0.001	0.001	0.001	0.001	0.001	0.005	0.003	0.040	0.080
0.002	0.068	0.011	0.002	0.002	0.002	0.002	0.002	0.011	0.005	0.079	0.158
0.003	0.103	0.016	0.003	0.003	0.003	0.003	0.003	0.016	0.008	0.117	0.235
0.004	0.137	0.021	0.004	0.004	0.004	0.004	0.004	0.021	0.011	0.155	0.311
0.005	0.168	0.026	0.005	0.005	0.005	0.005	0.005	0.026	0.013	0.190	0.380
0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.008
0.001	0.030	0.005	0.001	0.001	0.001	0.001	0.001	0.005	0.002	0.035	0.070
0.002	0.060	0.009	0.002	0.002	0.002	0.002	0.002	0.009	0.005	0.069	0.138
0.003	0.090	0.014	0.003	0.003	0.003	0.003	0.003	0.014	0.007	0.108	0.217
0.004	0.120	0.019	0.004	0.004	0.004	0.004	0.004	0.019	0.009	0.143	0.286
0.005	0.147	0.023	0.005	0.005	0.005	0.005	0.005	0.023	0.011	0.174	0.349

Table 2

Expanded uncertainty in generated temperature and relative humidity							
		Expanded uncertainty in generated relative humidity, %rh					
Temperature	Nominal %rh	2	20	40	60	80	98
Nominal value °C	Expanded uncertainty °C						
1	0.08	0.01	0.13	0.25	0.37	0.49	0.60
20	0.08	0.02	0.06	0.21	0.32	0.42	0.51
40	0.08	0.01	0.10	0.19	0.28	0.36	0.44
60	0.08	0.01	0.08	0.16	0.24	0.32	0.38
80	0.08	0.01	0.07	0.14	0.22	0.29	0.35

8 CONCLUSION

The relative humidity facility at NPL has now been validated and can provide traceability for rh hygrometers directly against the national standard. The instruments that can be calibrated range from remote sensing psychrometers requiring high flow rates to electronic rh probes which only need a small sample of calibration gas. The uncertainties of the new standard vary with the temperature and relative humidity but are in general better than 0.5% rh throughout the range.

Problems associated with leaks through instruments and cable feed through have been encountered and addressed.

The major components of the uncertainty have been identified and combined to conform to current accepted practice.

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10 REFERENCES

1 Stevens, M. and Bell, S.A., "The NPL standard humidity generator: an analysis of uncertainty by validation of individual component performance", *Meas. Sci. Technol. (1992), 3, 943-952 (1992)*

2 Stevens M and Armitage D, "Uncertainty evaluation of the NPL Standard Humidity Generator", *NPL Report MOT 7*, 1996

3 Stevens M and Armitage D, "Uncertainty evaluation of the NPL High Dew-point Humidity Generator", *NPL Report MOT 8*, 1996

4 Stevens M, "Improved flow rate monitoring if the High Dew point Generator", NPL Report CMAM 13

5 NIS 19, "Traceability of Humidity Measurement", edition 2, *United Kingdom Accreditation Service, 1995*

6 Gibbins C. J., "A survey and comparison of the relationships for the determination of saturated vapour over plane surfaces of pure water and of pure ice", *Annales Geophysicae, 1990, 8, (12), 859-886 (1990)*

7 Sonntag, D., "Important new values of the physical constants of 1986, vapour pressure formulations based on the ITS-90, and psychrometer formulae" *Z. Meterol. 40 (1990) 5, 340-344*

8 "Guide to the expression of uncertainty of measurement". *International Organization for Standardization, 1993*

9 M3003, "The expression of uncertainty and confidence in measurement", edition 1, *United Kingdom Accreditation Service, 1997*