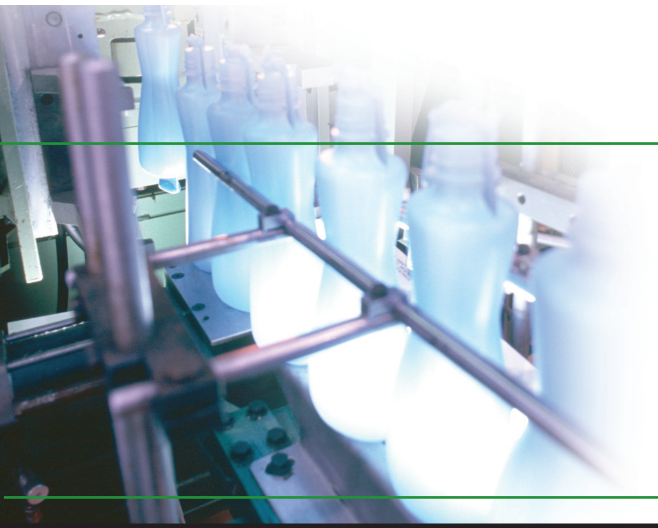

The Development of a Transportable Humidity and Temperature Generator

ENVIRONMENTAL
ANALYSIS

Blue Ramsey & Robin Farley, Rotronic Instruments (UK) Ltd, London, UK
Unit 1A Crompton Fields, Crawley,West Sussex. RH10 9EE Tel: [44] 01293 571000

Abstract:

This paper describes the development and testing of a transportable humidity and temperature generator primarily used for the calibration of humidity instrumentation in laboratories and on-site.

The unit is capable of generating humidity and temperature environments over the ranges 0…60°C and 2…95%rh, and is fully self-contained, requiring only an electrical supply. The design of both the temperature and humidity control systems are discussed, including how many of the inherent difficulties in achieving stable control in a small chamber have been overcome.

Test methods and data are presented to show how the key performance issues of temperature control stability and temperature gradients can both be specified to be better than ±0.1°C. Included is a presentation of an uncertainty budget, with worked examples based on %rh probe and chilled mirror transfer standards.

Keywords: Transportable, Humidity, Generator, Calibration, HygroGen.

1. Introduction

As demand for %rh calibration has grown, certain application scenarios have led to the development of dynamic generators of %rh and temperature. As suppliers of %rh and temperature instrumentation to many of the worlds leading pharmaceutical companies, Rotronic were frequently asked for more convenient and rapid methods of humidity and temperature calibration. In particular there was need for a system that could maintain fixed temperature conditions whilst %rh calibration was performed. Typically %rh calibration has been carried out using salt based systems, but practical issues restrict their use in some scenarios and the time to reach equilibrium can be impractical.

In facilities with large numbers of %rh transmitters requiring regular routine calibration, the stabilisation time of salt solutions meant that an instrument calibration could take many hours. This can render the control or monitoring system inactive for an extended period, or require that transmitters were 'swapped out' for the duration of the calibration in a laboratory or workshop. Both issues are not ideal, so the user demand was for a transportable means of generating stable temperature and humidity conditions.

The specification of the HygroGen was defined to at least meet the specific requirements of the standard pharmaceutical stability test conditions, the limits being 10 to 45°C and 5 to 90%rh. The target for control stability was better than ±0.2°C and temperature gradients of ±0.2.

The principal adopted for the development of the HygroGen was of a dynamic, active system, with capacity for rapid changes in chamber conditions. As relative humidity is dependent on temperature, thermal stability was given a high priority.

2. Thermal System

The thermal pump system designed for the HygroGen is solid state, peltier based. Practically, heat pumps are often limited by poor heat transfer to and away from the peltier element. Through choice of materials and engineered thermal interfaces between the pump components, the HygroGen is capable of delivering a high difference (dT) in temperature between the hot and cold sides.

The use of a high specification heat pump is of little consequence if the chamber space is not well thermally isolated. Of critical importance are the thermal mass and thermal conductivity of the chamber assembly. The first is the energy stored at a given temperature, and hence the amount of energy necessary to be moved to achieve a given change in temperature. The second determines the rate at which heat energy will flow between the external environment and the chamber for a given dT. The HygroGen chamber utilises a double insulated construction to minimise heat flow and ensure a low thermal mass in the internal chamber.

This construction is different to a water jacket/bath assembly in that it will respond quickly to changes in temperature set points. The specific heat of water is 4.2x10^3 J•Kg^{-1}K^{-1} compared to air ≈1.4J•Kg^{-1}K^{-1}, given that air is 1000th the density of water, the heat energy stored in a given volume of water, at a given temperature will be 3x10^6 times greater than the same volume of air (at atmospheric temperature) at the same temperature. Thus a fast responding water bath configuration will need a far more powerful heat pump assembly to effect rapid change, a requirement at odds with a fast reacting, portable design.

Transfer of energy between chamber assembly and heat pump occurs through air, a notoriously poor thermal transfer medium, and the reason why temperature calibration baths use liquid. Thus it becomes critical that the air in the chamber is well circulated over the heat-pump and over the internal chamber surfaces. In the HygroGen this achieved by the internal chamber fan and airflow sleeve, which is designed to circulate the air such that the air is passed immediately over the heat-sink before travelling over the internal chambers surface prior to being returned through the central measurement area to the fan. This circulated air bath ensures all the internal surfaces receive airflow, which in turn minimises thermal gradient. The fan itself contributes heat energy to the system and ideally the motor for the fan would reside outside the chamber, size and cost make this impractical on the HygroGen and the additional heat energy is absorbed in the overcapacity of the heat pump.

3. Humidity System

The humidity system is comprised of a drying and a wetting section. Drying is achieved through passing an air stream from the chamber through molecular sieve desiccant cell (Fig 1) and back to the chamber. Principle design considerations were the ease with which the desiccant could be replaced, and the minimisation of the complexity of the returned dry air path. The efficiency of the drying is determined by the capacity of the desiccant.

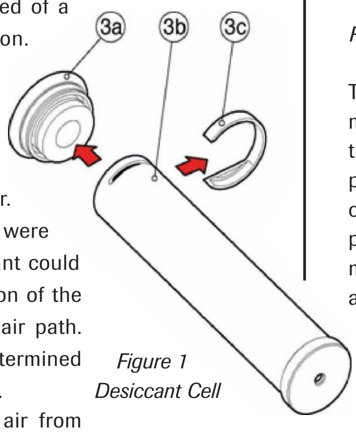

Figure 1
Desiccant Cell

The wetting section draws air from the chamber into a humidifier, which increases the water content of the air, before returning it to chamber. The humidifier is based on a piezo-electric vibrator. This causes micron size droplets to be vibrated free of the water surface. These then evaporate in to the air in the humidifier. The humidification control manages both the humidification pump and the piezo element to match airflow and water content to the required chamber set-point. This system allows extremely rapid saturation, at ambient temperatures. It avoids the slow response times of other ambient temperature humidifiers, and the thermal mismatch of heated humidifiers, which can disrupt the thermal equilibrium of the chamber during humidity changes.

Careful control of air flow velocity ensures that the humidified air is travelling slowly, to reduce moisture drop out, whilst the air flow in the humidifier is turbulent to ensure a high uptake of water in to the air. In addition the humidification system is isolated from the chamber if a low relative humidity target is set. This allows the HygroGen to easily reach low humidity across the entire temperature range, and with a factory upgrade achieves relative humidity as low as 0.8 %rh.

4. Ergonomics & Operator Interaction

Figure 2: Rack-mount HygroGen

The instrument has been designed to simplify interaction as much as possible. Cognitive Walk Through and Task Analysis tools have been applied to simplify all of the commonly performed operations. Functions are grouped according to commonality and expected frequency of use. Commonly performed operations can all be achieved via the front of the machine, as can replenishing the water and desiccant. The area of highest interaction is the chamber door area. The IEC inlet, and electrical sockets for the controller and three probes are at the top rear of the HygroGen, as are the sample loop connections.

The HygroGen is easily connected to a PC and controlled and logged via Ethernet, and optionally upgraded to include a fully autonomous asynchronous ramp soak 20 program, 50 step programmer facility in the controller. The controller is OPC/SCADA compatible, enabling the HygroGen to be integrated in to larger instrument installations.

Two case designs have been produced. The fully welded stainless steel enclosure minimises the ingress of spilt fluids/powders and provide a wipe-down surface suitable for use in clean areas. The rack-mount version (Fig 2) is a more conventional wrap over design, with front panel mounting points for a 19" rack.

Feedback from customers has been used to revise elements of the HygroGen, particularly the door, controller functions and chamber air flow.

5. Performance Envelope

The specification of the HygroGen was defined to at least meet the requirements of the standard pharmaceutical stability test conditions, the limits being 10 to 45°C and 5 to 90%rh. Our target for control stability was better than ±0.2°C and temperature gradients of less than ±0.2 °C. Also of importance was the time taken to reach and stabilise set-points, an important factor on productivity where multiple point calibration of instruments is required.

The HygroGen exceeds the initially specified operating ranges, having a maximum temperature range of 0 – 60°C and a 1 – 95 %rh capability as illustrated in figure 3.

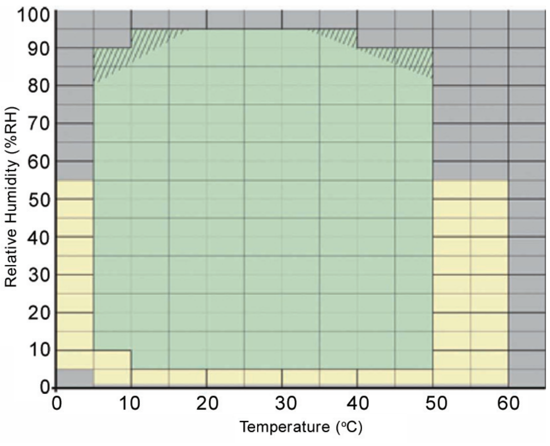

Figure 3: HygroGen operating ranges

6. Response Time

Rapid responses to changes in temperature and relative humidity targets were a requirement of the original brief; the HygroGen achieves these across a wide operating range, outperforming alternative products. This allows the rapid multipoint calibration of sensors, and minimal time spent waiting for the chamber to re-equilibrate after probes or loggers to be calibrated are swapped.

Figure 4 illustrates the rapid thermal response of the chamber work space to a change in target temperature. The rate of change is dependent on the ambient and chamber temperatures, but even the extreme operating ranges of the HygroGen are reached within 15 minutes (0 - 60°C) or 40 minutes (60 – 0°C).

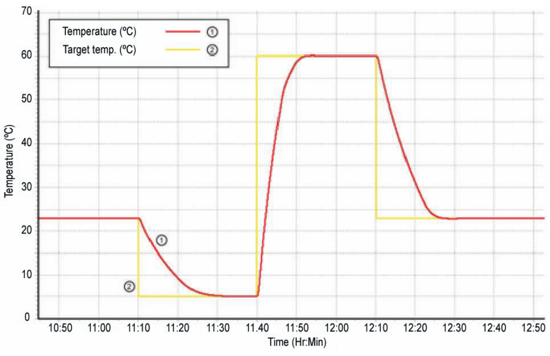

Figure4: HygroGen sample plot of temperature response to step change set-points (ambient 20°C)

The typical time to target for relative humidity changes are illustrated in figure 5, and are usually completed within 5 minutes. High and low relative humidities will take longer to achieve at high and low temperatures. Also note the negligible disruption to the thermal control incurred by the changes in rh.

7. Control Stability

To achieve a steady state condition at the desired set-points it is necessary to have stable control, this is partly a function of the control algorithm and PID values but it is also a function of the control signals. The HygroGen allows the PRT to be given multipoint calibration values, and/or a global offset. As relative humidity is highly temperature dependent, it is vital that the temperature in the chamber fluctuates as little as possible. Figure 6 illustrates the control stability of the temperature and relative humidity loops, typically ± 0.005 or less for thermal stability and ± 0.05% or less for humidity.

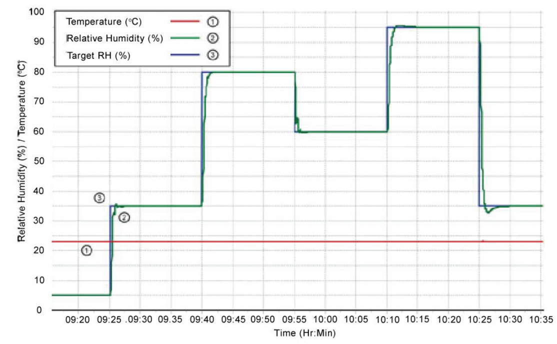

Figure 5: HygroGen sample plot of relative humidity response to step change set-points (ambient 20°C)

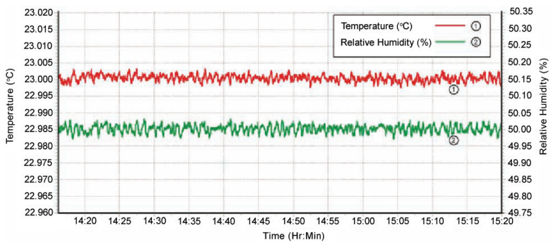

Figure 6: HygroGen sample plot of temperature and relative humidity control stability

8. Temperature Gradient

Of critical importance within a chamber is the temperature gradient. This has been minimised as much as possible through the design of the chamber, door and airflow sleeve. However it will also be influenced by external factors such as stem conduction and ambient temperature. Typically the temperature variation in the working space occupied by five HygroClip probes inserted through the door, to a depth of 120mm is less than 0.1 °C at a chamber temperature of 5°C, and better than 0.05 °C at 23 °C (ambient 20°C).

Profiling the whole working space required the development of a specific test procedure. Using a six PRT array connected to an ASL F200 bridge, a series of measurements can be performed to establish the temperature gradients within the chamber. As can be seen in Figure 7, the PRT's are positioned in the extremes of the working space to provide worst case measurement data. Cables are routed through a probe insertion port and sealed with non-hygroscopic putty. Maximum, Minimum and Standard Deviation are used to define the temperature gradients.

Figure 7: Six PRT array used to measure 5 temperature gradients

9. Uncertainty

The uncertainty assigned to the values generated by the HygroGen as part of a traceable or accredited calibration system will of course depend on many factors, most significantly the type of reference instrumentation used. Detailed in Appendices 1 and 2 are examples of uncertainty budgets based on two measurement scenarios, %rh probe and dew point mirror references.

10. Customer Specific Solutions.

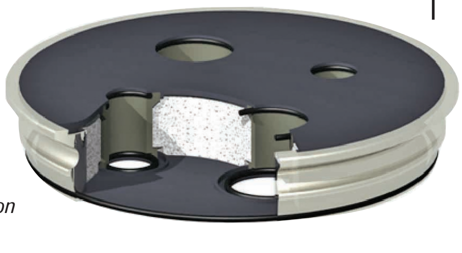

Figure 8: HygroGen chamber door detail Illustrating the double 'O' ring seal, low thermal transfer sleeves and insulation

To accommodate the wide range of probes that may require calibration, the chamber door is easily interchangeable, with a variety of port sizes and positioning available, or the option to build to order for specific applications. Figure 8 illustrates the standard door construction, showing the thermal insulation and 'O' ring seals to ensure the chamber remains sealed from the outside environment. Both the thermal insulation and gas tight seal are critical to optimum performance, particularly at the high and low ends of the temperature range. When the probe ports are not used, sealing 'bungs' are provided, and these are also insulated to achieve best measurement capability.

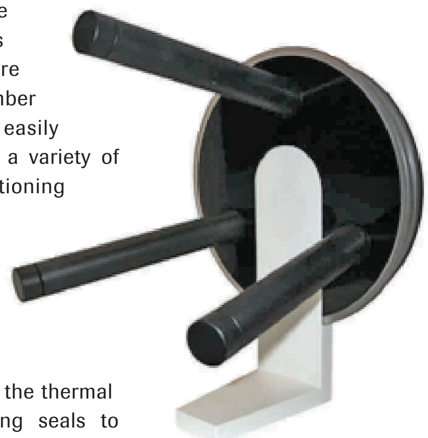

Figure 9: HygroGen custom door to accommodate three 12mm duct type transmitters

Figures 9 and 10 shows examples of two custom door options for specific uses, Figure 9 is a door specifically for calibrating duct type transmitters, where the client did not wish to remove the sensor from the probe assembly. The angled ports allows for three probes (each with a large cast aluminium base) to be calibrated simultaneously, whilst the long sheath around each port minimises thermal stem conduction by insulating the metal stem from the ambient environment. Figure 10 has 5 adjustable 'gland' type ports for accommodating any probe diameters from 9 – 17 mm. Other door options include clear doors for reading data loggers with integrated displays placed in the chamber, and combinations of specific sizes of ports from 3 to 30 mm, able to accommodate anything from a pt100 probe to an MBW chilled mirror head.

Figure 10: HygroGen custom door showing five adjustable probe glands 9 – 17mm

11. Conclusions

The HygroGen has exceeded many of the initial design specifications and benefits from continuous development thanks to a short communication path between the marketing and development teams. Customers have also provided a useful flow of information and feedback to further assist in developing the instruments best measurement capability. In most cases design improvements have been integrated into early instruments when routine maintenance is performed. The availability of custom chamber doors means the HygroGen can accommodate almost any humidity probe or data logger, and this has proven to be highly popular with users of many different manufacturers equipment.

The HygroGen offers a convenient and transportable means of generating stable humidity and temperature conditions, and with careful consideration of the various components of uncertainty, can form the basis of an accredited calibration both in laboratory and on-site situations. The provisional uncertainty budgets shown in the Appendices demonstrate a high potential capability in combination with a chilled mirror reference instrument, and good capability using a %rh based transfer standard.

Appendix 1

Provisional uncertainty in HygroGen at 20°C and 50% rh using a relative humidity probe as the humidity reference instrument

Overall uncertainty of temperature measurement

Uncertainty source	Value	Units	Sensitivity	Distribution	divisor	One SD	squared
PRT calibration	0.080	°C	1.00	normal	2.00	0.040	0.002
PRT and bridge repeatability	0.010	°C	1.00	normal	1.00	0.010	0.000
PRT drift	0.040	°C	1.00	rectangular	1.73	0.023	0.001
PRT linearity	0.007	°C	1.00	rectangular	1.73	0.004	0.000
Bridge calibration	0.010	Ω	2.60	normal	2.00	0.013	0.000
Bridge drift	0.004	Ω	2.60	rectangular	1.73	0.006	0.000
Bridge linearity	0.002	Ω	2.60	rectangular	1.73	0.003	0.000
Temperature coefficient of bridge	0.005	Ω	2.60	rectangular	1.73	0.008	0.000
Resolution of bridge	0.001	°C	1.00	rectangular	1.73	0.001	0.000
Temperature gradients in HygroGen chamber	0.100	°C	1.00	rectangular	1.73	0.058	0.003
Temperature fluctuations in HygroGen chamber	0.020	°C	1.00	normal	1.00	0.020	0.000
				Standard uncertainty		0.079	0.01
				Expanded uncertainty		**0.16 °C**	**95% confidence**

Overall uncertainty of humidity measurement

Uncertainty source	Value	Units	Sensitivity	Distribution	divisor	One SD	squared
Humidity probe calibration	1.00	% rh	1.00	normal	2.00	0.500	0.250
Humidity probe repeatability	0.30	% rh	1.00	normal	1.00	0.300	0.090
Humidity probe drift	0.50	% rh	1.00	rectangular	1.73	0.289	0.083
Humidity probe linearity	0.30	% rh	1.00	rectangular	1.73	0.173	0.030
Temperature coefficient of the relative humidity probe	0.30	% rh	1.00	rectangular	1.73	0.173	0.030
Resolution of the relative humidity probe	0.10	% rh	1.00	rectangular	1.73	0.058	0.003
Temperature gradients in HygroGen chamber	0.10	°C	3.25	rectangular	1.73	0.188	0.035
Temperature fluctuations in HygroGen chamber	0.02	°C	3.25	normal	1.00	0.065	0.004
Stabilisation criterion for reference probe	0.10	% rh	0.00	rectangular	1.73	0.000	0.000
Stabilisation criterion for probe under test	0.30	% rh	1.00	rectangular	1.73	0.173	0.030
				Standard uncertainty		0.746	0.56
				Expanded uncertainty		**1.49**	**95% confidence**

Appendix 2

Provisional uncertainty in HygroGen at 20°C and 50% rh using a chilled mirror reference instrument

Overall uncertainty of temperature measurement

Uncertainty source	Value	Units	Sensitivity	Distribution	divisor	One SD	squared
PRT calibration	0.080	°C	1.00	normal	2.00	0.040	0.002
PRT and bridge repeatability	0.010	°C	1.00	normal	1.00	0.010	0.000
PRT drift	0.040	°C	1.00	rectangular	1.73	0.023	0.001
PRT linearity	0.007	°C	1.00	rectangular	1.73	0.004	0.000
Bridge calibration	0.010	ø	2.60	normal	2.00	0.013	0.000
Bridge drift	0.004	ø	2.60	rectangular	1.73	0.006	0.000
Bridge linearity	0.002	ø	2.60	rectangular	1.73	0.003	0.000
Temperature coefficient of bridge	0.005	ø	2.60	rectangular	1.73	0.008	0.000
Resolution of bridge	0.001	°C	1.00	rectangular	1.73	0.001	0.000
Temperature gradients in HygroGen chamber	0.100	°C	1.00	rectangular	1.73	0.058	0.003
Temperature fluctuations in HygroGen chamber	0.020	°C	1.00	normal	1.00	0.020	0.000
				Standard uncertainty		0.079	0.01
				Expanded uncertainty		**0.16 °C**	**95% confidence**

Overall uncertainty of humidity measurement

Uncertainty source	Value	Units	Sensitivity	Distribution	divisor	One SD	squared
Mirror uncertainty	0.10	°C dp	3.52	normal	2.00	0.176	0.031
Mirror repeatability	0.05	°C dp	3.52	normal	1.00	0.176	0.031
Mirror drift	0.10	°C dp	3.52	rectangular	1.73	0.203	0.041
Mirror linearity	0.02	°C dp	3.52	rectangular	1.73	0.041	0.002
Mirror Resolution	0.01	°C dp	3.52	rectangular	1.73	0.020	0.000
Temperature gradients in HygroGen chamber	0.10	°C	3.25	rectangular	1.73	0.188	0.035
Temperature fluctuations in HygroGen chamber	0.02	°C	3.25	normal	1.00	0.065	0.004
Stabilisation criterion for reference probe	0.10	% rh	0.00	rectangular	1.73	0.000	0.000
Stabilisation criterion for probe under test	0.30	% rh	1.00	rectangular	1.73	0.173	0.030
				Standard uncertainty		0.418	0.17
				Expanded uncertainty		**0.84 %rh**	**95% confidence**