

REPORT

Improved flow rate monitoring of the NPL High Dew-point Generator

M Stevens

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ABSTRACT

The High Dew-point Generator operated by the National Physical Laboratory requires many parameters to be carefully monitored to enable a calibration service for hygrometers to be offered with an acceptable uncertainty. One such parameter is the recirculation flow rate through the generator. Until now this has been measured using a hot wire anemometer. The limiting factor of this instrument is that it will not operate above 60 °C but the generator itself works up to 82 °C. For this reason it is desirable to obtain an alternative measuring instrument that will operate over the full range of the generator. This report considers the measuring devices available, identifies an appropriate instrument and reports the results of the flow measurements at different temperatures. This project has been initiated as part of the DTI's National Measurement System Programme for Mass, 1996 to 1999, project 4, Humidity Standards.

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Centre for Mechanical and Acoustical Metrology
National Physical Laboratory
Teddington, Middlesex
United Kingdom
TW11 0LW

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Approved on behalf of Managing Director, NPL
by Dr Graham Torr, Head, Centre for Mechanical and Acoustical Metrology

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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 humidity 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 institutions in other countries. The principle of operation of these dew-point generators is to saturate a gas (commonly air) with water vapour at a known temperature and pressure. Saturation of the gas is achieved by forcing the gas through a coiled pipe in which a moisture source is located. Many parameters need to be measured to enable the dew point to be known to an acceptable uncertainty [1,2]. Some measurements are needed to be made with a very small uncertainty, for example the temperature of the gas exiting the saturator coil, while for some the repeatability of a condition is of greater interest, for example the recirculation flow rate through the generator.

Monitoring of the recirculation flow rate in the High Dew-point Generator (HDG) has been achieved until recently by the use of a hot wire anemometer. This instrument does not operate well at temperatures over 60 °C but the HDG is required to function at temperatures in excess of 82°C. In view of this, consideration has been given to a replacement flow measuring instrument that will operate over the full temperature and flow range of the HDG. This report describes the selection of a replacement flow measuring instrument and the assessment of its performance.

2 BACKGROUND

NPL presently operates two dew-point generators which cover the calibration range -75 °C to 82 °C. The High-range Dew-point Generator operates from -3 °C to 82 °C and is a recirculating generator. The Standard Humidity Generator (SHG) covers the whole of the calibration range, and can be used in both recirculating and single pass modes. The operation and uncertainty analysis of the two generators have been detailed in ref. [1] and [2].

In a fully recirculating generator eventually the system will reach equilibrium, saturating the gas at the temperature of the moisture source which is maintained at the coldest temperature of the system. The operation of the NPL generators is different to this ideal system. A small portion of the saturated gas is bled off to instruments under test and exhausted to atmosphere. Operating in this way has the advantage that any contamination from the instrument under test is not fed back into the generator. The bled-off gas is replaced with gas from a pre-saturator at nominally the same dew-point temperature. The accuracy with which the pre-saturation can be achieved is not comparable with the uncertainty of the generator itself and therefore some disturbance to the equilibrium will take place. This being the case, the efficiency of different aspects of the system must be known in order to estimate the overall uncertainty of the generator itself. One such element, and the subject of this report, is the recirculation flow rate through the HDG. The speed of the gas in the saturator coil will affect the temperature conditioning efficiency, the effectiveness of mixing the top up gas with the recirculating gas, the self-heating of the platinum resistance thermometers (perts) measuring the generated dew point and the efficiency of the saturation process itself.

Prior to this investigation the speed of the gas in the generator was measured using a hot wire anemometer. The temperature range of this instrument is 0 °C to 60 °C. However the temperature range of the generator is from -3 °C to 82 °C with a possibility of extending the range to 90 °C. The flow rates at temperatures above 60 °C were derived from the settings on the

recirculation fan motor. These settings were first calibrated against the hot wire anemometer at the lower temperatures but the density of the gas changes with the dew point and temperature making the uncertainty of the process less well defined at the high temperatures.

Another problem inherent with the direct measurement made by the hot wire anemometer is that the calibration curve of this type of instrument changes with repeated variations in temperature and such variations are part of the operation of the HDG.

In the future the HDG is to provide relative humidity (rh) calibrations for rh probes and psychrometers. The measurement of flow rate during this operation is critical as this will affect the performance of the instruments themselves.

3 TYPES OF FLOW METER

The flow rate of a fluid can be defined by a number of terms which are appropriate to different applications. Each measured quantity can be converted into another, given sufficient knowledge of the system being used. The range and choice of flow meters is vast but their operating principles can be separated into 6 main types.

- Constriction type
- Velocity meters
- Mean velocity meters
- Variable area flow meters
- Quantity flow meters/ volumetric meters
- Mass flow meter

4 CHOICE OF FLOW METER

The critical parameter associated with the flow in the HDG is the velocity of the flow in the rh test chamber, as specific conditions need to be simulated when calibrating psychrometers. The local velocity measurements needed could in principle be derived from mean velocity measurements or from volumetric or mass flow measurements, but to achieve the desired accuracy the velocity profile of the chamber will need to be known. This profile will change if a different shape of instrument is placed in the test chamber. For this reason "local" velocity meters are the preferred choice. Typically, the velocity to be measured will be in the range from 2 to 10 m s⁻¹.

At present there are no UKAS laboratories accredited for air velocity calibrations. Repeatability tests on velocity meters can be carried out in-house against the calibrated mass flow meter used in the SHG.

When the generator is used for dew-point calibrations, the absolute value of the gas flow is not critical but the repeatability of condition is. It would be sensible and economic to measure one parameter for both rh and dew point calibrations.

One problem associated with many flow meters is that in order to measure the flow an obstruction is placed in the flowing gas stream. The obstruction will cause a pressure differential between the up-stream and the down-stream gas. This pressure change will affect the dew point of the gas. It is therefore desirable for the flow measurement device to have a small pressure differential across it. This factor will eliminate most of the commercial flow meters on the

market. Practical limitations of many of the devices will also make them unsuitable for this application.

4.1 Hot wire anemometer

A very fine electrical resistance wire will be cooled when placed in a stream of gas. The rate of cooling is a function of the temperature difference between the gas and the wire and will be affected by the velocity of the gas. The wire is heated as part of a wheatstone bridge circuit and is cooled by the gas flowing over it. The rate of cooling is proportional to the gas velocity. These devices have a range from 0.03 m s^{-1} to supersonic flow rates. The instruments investigated have an operating temperature limit of 60°C with a manufacturers estimated uncertainty of measurement of better than 0.5%. The hot wire anemometer investigated has three main advantages:

- measures velocity
- compact
- accurate

The main disadvantages of this instrument are:

- not designed to be sealed (this is necessary to reduce uncertainty due to leaks in the generator)
- will not cope with desired temperature range

4.2 Pitot-static tube

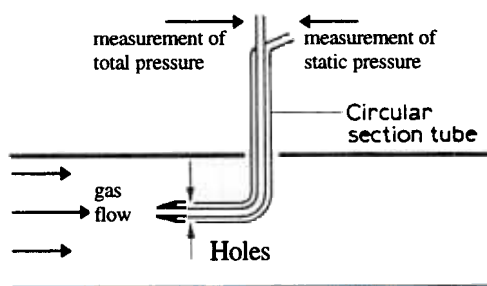


FIG 1

A pitot-static tube (fig 1) combines “total” and “static” pressure measurements in one probe in order to find the local velocity of the flow. The instrument consists of two concentric tubes, the outer tube has a series of holes perpendicular to the direction of flow. The inner tube faces the direction of the flow and transmits the sum of the static and dynamic pressures while the annular space between the two tubes transmits the static pressure only. From measurements of the pressure differential between the tubes the velocity head or pressure head produced by the loss in kinetic energy can be determined and the velocity of the fluid can be calculated. The manufacturers estimated best measurement capability for this type of device is 0.5% over the range 1 to 60 m s^{-1} .

The pitot static tube investigated has three main advantages:

- will work over the temperature range
- measures velocity
- compact will fit in temperature controlled bath

The main disadvantages of this instrument are:

- the gas being monitored is saturated so the pitot-static tube inlet ports would have to be big enough to avoid clogging up with water
- accuracy is less than a hot wire anemometer

5 DISCUSSION

Commercial hot wire anemometers are not specified to cover the temperature range needed and are therefore not appropriate for the application.

The pitot-static tube will operate over the full temperature range of the HDG and will perform to the accuracy required. It is also the cheapest of the devices considered but the least accurate.

The flow through the HDG needs to be turbulent in order to limit the static boundary layer at the temperature conditioning pipe surfaces and at the surface of the water in the saturator coil. To aid this and to limit the size of the HDG the conditioning pipes are split into 4 smaller pipes with an equivalent total area and are also coiled. Inside the coiled saturator are flow diverters to induce turbulence and force the gas onto the water surface. The turbulent nature of the flow complicates the measurement, a device that measures local velocity will give a fluctuating reading and with certain flow conditions could experience local flow anomalies where the readings will not be representative of the flow in the rest of the generator. It would therefore be necessary to measure the flow at different sections throughout the HDG to obtain a more realistic measurement.

Automatic monitoring of the flow rate is necessary to enable the flow characteristics of the system to be studied in more detail. The devices investigated have analogue voltage outputs that could be easily measured by the HDG monitoring system multimeter. In order to measure more than one output the input to the multimeter will need to be switched. For this purpose a multiplexer that can be controlled by the monitoring computer is required.

6 RESULTS

6.1 Location of the measuring instruments

Two pitot-static tubes have been placed in the recirculation path of the generator. One is located between the impeller and the entrance to the split temperature conditioning tubes. The body of this pitot-static tube that protrudes from the saturator coil is submerged in the fluid bath for temperature conditioning. The second pitot-static tube is placed in the pipe leading to the rh bath. Careful temperature control of this pitot-static tube and pipe using electrical heated lines is necessary to prevent condensation from the flowing gas. When psychrometers are to be calibrated a third pitot-static tube will be incorporated in the rh test chamber.

6.2 Assessment of measurement results

The fluctuation of the readings due to the turbulent flow is approximately $\pm 1 \text{ m s}^{-1}$ and the average agreement between the two flow meters when the bath is at 82°C is within 1 m s^{-1} . The

generator temperature was cycled over its full range and the measured values repeated to within the fluctuations of the readings. The repeatability of the measured flow at defined impeller motor settings was in the order of $\pm 1 \text{ m s}^{-1}$ which is similar to that obtained with the hot wire anemometer.

The results of measurements using the pitot-static tubes at temperatures above 60 °C show that as the temperature rises the velocity of the gas reduces by several metres per second while using a constant impeller motor setting. The evaluation of the HDG [2] was undertaken using the same impeller motor settings throughout the temperature range. This, linked with the recent measurements, indicates that the velocity of the recirculating gas has a minimal effect on the performance of the HDG and that the uncertainty in the flow measurement has little effect on the generated dew point.

One issue that has that has a significant effect at higher dew-point temperatures is that moisture from the generator diffuses into the tubes which connect the measuring head of the pitot-static tube to its differential pressure transducer. After several hours sufficient moisture has accumulated in these tubes to block them. This does not usually affect the present operation of the HDG. It may become significant during operation at higher temperatures, but the problem can easily be overcome by appropriate use of insulated electrical heating.

To automate the data collection from the instruments the analogue output is monitored by the system multimeter. In order to monitor more than one device a multiplexer is used to switch the outputs from the different flow meters to the multimeter. In this way the readings from each flow meter can be automatically monitored enabling easier analysis of the variations in the flow rate.

7 CONCLUSION

The results of the measurements carried out show that the pitot-static tubes work effectively over the full range of operating temperature of the HDG. The uncertainty with which the flow rate can be measured by the pitot-static tubes has been shown to be well within that needed to ensure correct operation of the HDG as a dew-point generator. The agreement between the two instruments situated in different parts of the generator is within the uncertainties needed. The problems encountered with diffusion of moisture into the tubes of the differential pressure measurement can easily be overcome when necessary.

The measurement of the flow rate and flow profile in the rh chamber are being considered as part of project 2M042 but the present project has helped to develop the techniques and instrumentation necessary to achieve this.

8 ACKNOWLEDGEMENTS

This work has been performed within the DTI's National Measurement System Programme for Mass, 1996 to 1999, project 4, Humidity Standards, sub-project 4.1. The flow rate and flow profile in the HDG during rh measurements will be further considered under sub-project 4.2 of the same programme.

9 REFERENCES

- [1] M Stevens and D Armitage, Uncertainty evaluation of the NPL Standard Humidity Generator, *NPL Report MOT 7*, 1996
- [2] M Stevens and D Armitage, Uncertainty evaluation of the NPL High Dew Point Humidity Generator, *NPL Report CMAM 8*, 1998