REPORT

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Design, Construction and Testing of a Humidity Management System for Ultrafine Particle Field Measurements

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Design, Construction and Testing of a Humidity Management System for Ultrafine Particle Field Measurements

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ABSTRACT
The design, construction and testing of a humidity management system for airborne ultrafine particle field measurements is described. The system was designed to allow modification of commercially available ultrafine particle counters and sizers deployed on the UK particle counting and sizing network such that they meet the recommendations of the academic group EUSAAR, whilst supporting the other objectives defined by Defra.

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Introduction

The UK air quality networks measure a range of atmospheric pollutants and fall under the responsibility of the Department for Environment, Food and Rural Affairs (Defra). Many pollutants are measured in response to legislative requirements, but other networks are operated for research purposes. The particle counting and sizing network falls into this category, and this report describes the construction and testing of an upgrade to the network to align the measurements with a group known as EUSAAR (European Supersites for Atmospheric Aerosol Research).

EUSAAR is an EU-funded Integrated Infrastructures Initiative project that aims to harmonise various aspects of airborne particulate measurement. The strand of the project of interest here relates to sub-micron size distribution and number concentration measurements, and is led by the group of Prof. Wiedensholer based at the Institute for Tropospheric Research in Leipzig. The UK's involvement in EUSAAR is via the Harwell monitoring site in Oxfordshire, through Prof. Roy Harrison (University of Birmingham), which has recently been added to the EUSAAR network. NPL is also an associate member of EUSAAR to facilitate collaboration and communication.

The EUSAAR recommendations for these measurements require addition of a humidity control and monitoring system and monitoring of several instrument parameters that are not normally required. This short report describes the outcome of the upgrade work.

Design and Specifications

The upgrade has been designed to meet the following general specifications:

- Improvement and standardisation of PM inlets throughout the network (TSP head + PM_1 cyclone)
- Drying of the incoming sample for both the CPC and SMPS (where present) using nafion driers to <40% Relative Humidity (% RH)
- Drying of SMPS sheath air using nafion driers to <40% RH.
- Monitoring of sample relative humidity.
- Additional recording of instrument parameters.

The main novel feature of the upgrade is the drier system. It is based around nafion driers as opposed to desiccants such as silica gel because this minimises the need for field maintenance. The system uses a pre-drier, sampler drier and sheath air drier (for SMPS only) with flows controlled via an array of rotameters. A block diagram of the upgrade is shown in Figure 1.

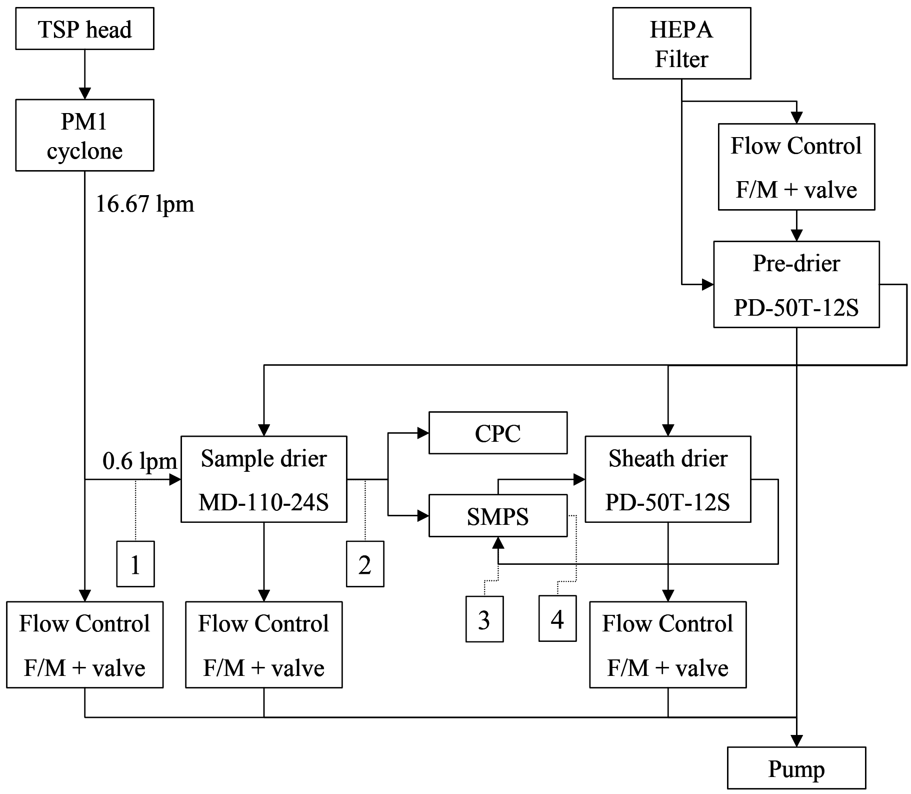

Figure 1: General Block Diagram of the EUSAAR upgrade system. The numbered boxed mark the locations of the humidity meters used to characterise the prototype system. Production systems only feature meter #2.

Laboratory Prototype

To evaluate the performance characteristics of the upgrade, a prototype system was built and tested at NPL. The test-bed stage prior to installation in a field-ready enclosure is shown in Figure 2. The prototype module varied only slightly from the others subsequently produced, and only in ways that would not affect instrument performance.

Stainless Steel Swagelok was used throughout, and Tygon tubing was used for the internal plumbing except downstream of the driers where PFA tubing was used. PFA tubing was not used throughout as this allows moisture to permeate through.

The prototype system was tested for two key performance characteristics: the penetration efficiency of particles through the sample drier and its humidity control characteristics.

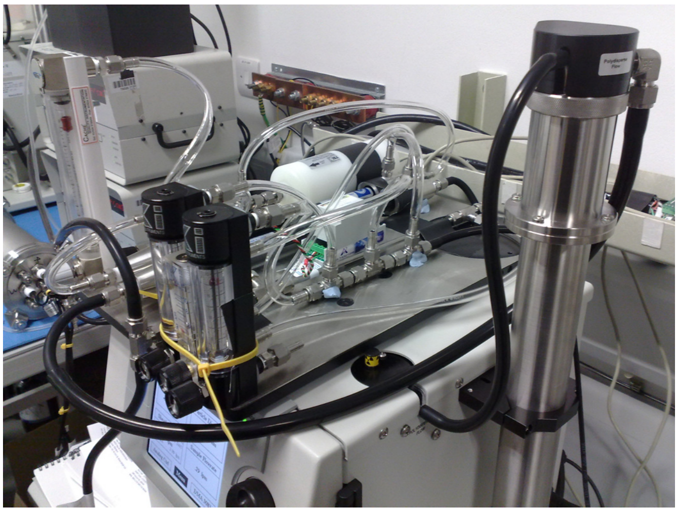

Figure 2: Laboratory prototype drier system

Sample Drier Penetration Efficiency

A particle transport efficiency of the system was tested using a challenge soot aerosol. The data recorded both with and without the sample drier was compared to yield a size-dependent relationship.

The first test used challenge aerosols of modest concentration (~8000 cm^{-3}) generated using a CAST2 soot generator. The SMPS and CPC used were a new TSI 3936L75 and TSI3022A respectively. Other than the use of a higher activity neutraliser in the SMPS, these are nominally identical to the network instruments. A pre-neutraliser was used to ensure that the sample did not carry excessive charge. For each of the three aerosols measured, the concentration was adjusted to ensure that it was safely within the CPC's single particle counting mode, over which good linearity can be expected. Furthermore, measurements were carried out such that drift in the output of the aerosol generator could be corrected. Each measurement consisted of 5 samples collected over a 15-minute period.

The SMPS results show that the size distributions obtained (Figure 3) were not significantly affected by the introduction of the drier system. This indicates that there should be no significant effect on data interpretation for particle size. From these, the size-dependent penetration efficiency can be determined (Figure 4). These data indicate that particle losses are small and generally <5%. Furthermore, there is a weak size-dependence meaning that a single penetration correction value may reasonably be applied to all size bins. Integration of these data to obtain the overall number concentration compare well to those obtained from the stand-alone CPC measurements, with the average penetration efficiencies being 97.7% and 100% for the SMPS and CPC respectively.

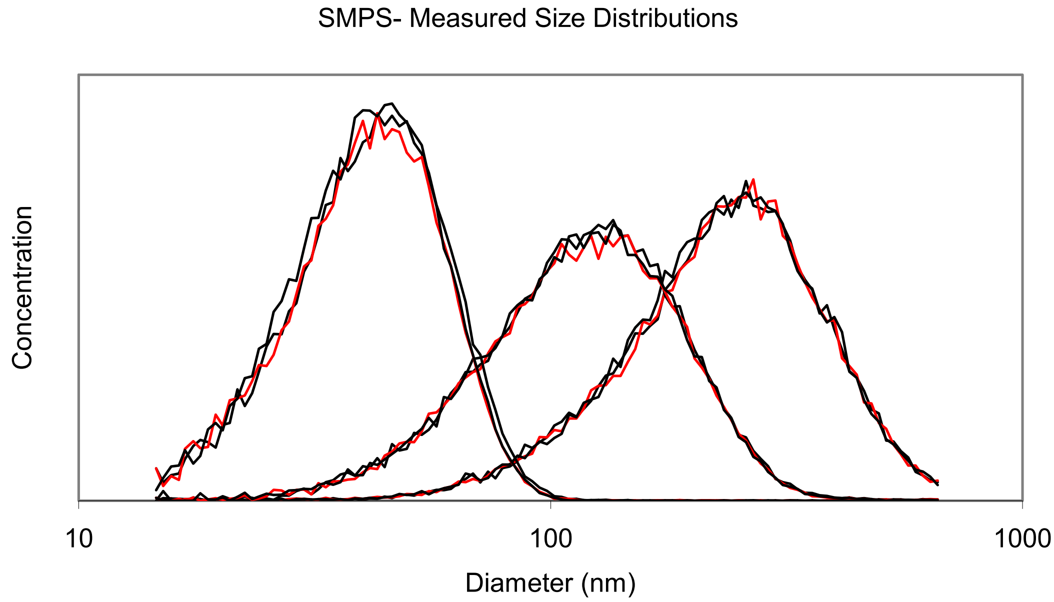

Figure 3: Effect of the sample drier on the measured size distribution for neutralised soot particles. Black lines are data collected without the drier present, and red lines with the drier.

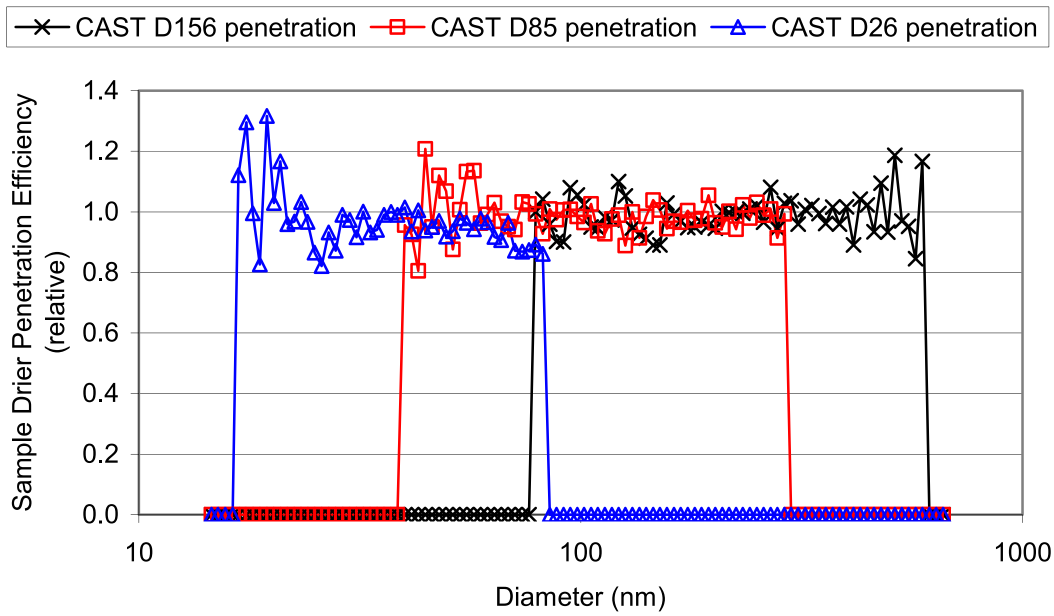

Figure 4: Size dependent penetration efficiency of particles through the sample drier.

Humidity Performance

The humidity performance of the upgrade is its most critical aspect. To test the response of the system to a range of challenge humidity levels, several sensors were mounted at key points in the system (Figure 1). An external nafion drier/humidifier was used to generate the challenge atmospheres ranging from <10% RH to >90% RH at room temperature. The results (Figure 5) demonstrate that the drier system performs well, with the humidity varying between 10% RH and 40% RH after the sample drier, and only between 15% RH and 25% RH after the DMA for a challenge humidity range from <10% RH to >90% RH.

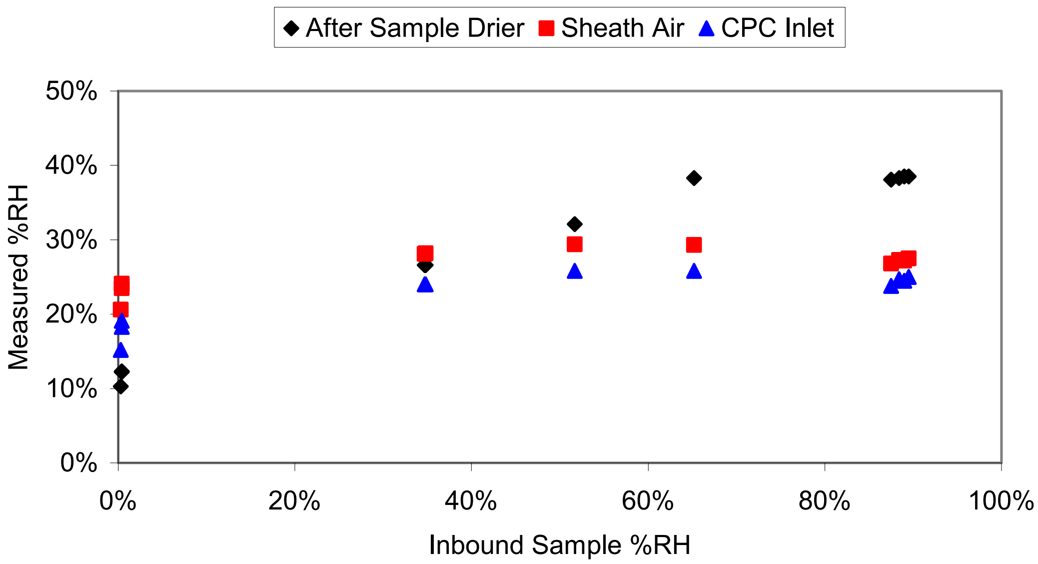

Figure 5: Humidity control performance of the laboratory prototype.

Production Units

The four production units were built into a suitable housing to allow field deployment (Figure 6). Three of the units were designed as a dual SMPS and CPC system, and the fourth a CPC-only system, but with basic work carried out to allow easy upgrade to the dual system if required. The testing of these units differed slightly from the testing carried out on the laboratory prototype to incorporate the lessons learnt. The largest difference was in the challenge aerosol used for the penetration calibration. Instead of a soot aerosol at three different sizes, a NaCl aerosol was used and the drift-correction measures improved. Humidity measurements were only taken immediately downstream of the sample drier. The results from all four units were self-consistent and meet the performance expectations.

Figure 6: A production SMPS drier system during calibration at NPL.

Serial #	Variant	Humidity Performance (%RH)			Penetration Efficiency (%)	
		Dry (<10% RH)	Ambient (~40% RH)	Wet (>90% RH)	SMPS	CPC
1	SMPS/CPC	30	37	40	99.1	93.8
2	SMPS/CPC	28	35	40	96.4	95.7
3	SMPS/CPC	27	31	35	100.0	95.9
4	CPC	30	32	30	--	96.0

Table 1: Collated results of the production unit calibrations