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Determination of the absolute accuracy of UK chamber facilities used in measuring methane emissions from livestock

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ABSTRACT

Respiration chambers are one of the primary sources of data on methane emissions from livestock. This paper describes the results from a coordinated set of chamber validation experiments which establishes the absolute accuracy of the methane emission rates measured by the chambers, and for the first time provides metrological traceability to international standards, assesses the impact of both analyser and chamber response times on measurement uncertainty and establishes direct comparability between measurements made across different facilities with a wide range of chamber designs. As a result of the validation exercise the estimated combined uncertainty associated with the overall capability across all facilities reduced from 25.7% ($k = 2$, 95% confidence) before the validation to 2.1% ($k = 2$, 95% confidence) when the validation results are applied to the facilities' data.

1. Introduction

Methane is a greenhouse gas (GHG) with a global warming potential 33 times that of carbon dioxide [1]. Agriculture is a significant contributor to global methane emissions as evidenced by the 2011 European Union inventory detailing that 50% of all methane emissions were attributable to the agricultural sector [2]. Currently in the UK livestock emissions (contributing ~85% of methane emissions from agriculture) are calculated using the Tier 1 approach [3] under the United Nations Framework Convention on Climate Change (UNFCCC). The Tier 1 approach is based on using emission factors (EFs) for different livestock categories and associated manures, i.e. no account is made with respect to farm activity or mitigation effort [3]. Consequently, the UK Government's Department for the Environment and Rural Affairs (DEFRA) have commissioned a programme of research to facilitate movement to a Tier 2 or 3 approach under UNFCCC – the Agricultural Greenhouse Gas Inventory Research Platform [4]. A key part of this research is work to underpin national measurement infrastructure to ensure that various UK facilities used for measuring livestock methane emissions are producing comparable data that is traceable to the international system of units and has quantified uncertainties, and this is reported here.

A generally accepted method for determining emissions is the respiration chamber where the animal is placed in the chamber with a controlled throughput of ambient air [5]. Measuring the concentration difference between the outlet and inlet combined with the flow rate gives the total

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emitted methane rate. Historically such chambers were used to estimate heat production for measurements of energy metabolism [6–9], which required precise and accurate measurements of oxygen consumption and carbon dioxide and methane production by animals housed in the chamber. However, due to the reasons outlined above the focus has now shifted towards using chambers to determine the impact of animal husbandry practises on methane emissions, often with simpler designs [10–12].

To truly understand the accuracy of any method and to establish the comparability between different measurement systems there must be comparison to an internationally accepted reference point. Historically, the accuracy of chamber measurements has been based on calibration of flow meters and analyser performance [8] and measurement of emissions obtained during a weighed release of the target gas into the chambers. McLean and Tobin [8] give an extensive review of recommended procedures at that time and Cammell et al. [7] summarise results for a number of published respiration chamber calibrations. More recently Hellwing et al. [13] report on the calibration of a simple respiration chamber for cattle. However, the work reported here is, to our knowledge, the first to provide metrological traceability to international standards, assess the impact of both analyser and chamber response times on measurement uncertainty, and establish direct comparability between measurements made across different facilities with a wide range of chamber designs. In addition, the combination of direct analyser calibration and controlled methane releases at different locations enable the performance of the main elements of the experimental system to be assessed independently and their relative contribution to the combined system uncertainty determined.

The aim of this work was to establish the performance and comparability of different UK chamber facilities. This paper describes the results from a coordinated set of chamber validation experiments conducted at 6 chamber facilities at 5 leading agricultural research centres around the UK.

2. Materials and methods

2.1. Chamber designs

All of the test chambers across the six facilities were based on the same basic design principle (Fig. 1), although there were marked differences in terms of size, flow conditions and age across the different facilities. In all cases, ambient air is drawn into the chamber and mixes with the emissions from the test subject before being vented to atmosphere via an extract duct. An flow meter (hot wire or vane based) is positioned in the extract duct to determine the chamber flow rate whilst an interfaced gas line is used to pump a sample of the extract gas through an analyser to determine the methane concentration. Combining the flow rate and concentration measurements allows the methane emission rate to be calculated using in-house methodologies. The details of the chamber designs and the differences between them are beyond the scope of this paper and are only discussed if relevant to the reported observations.

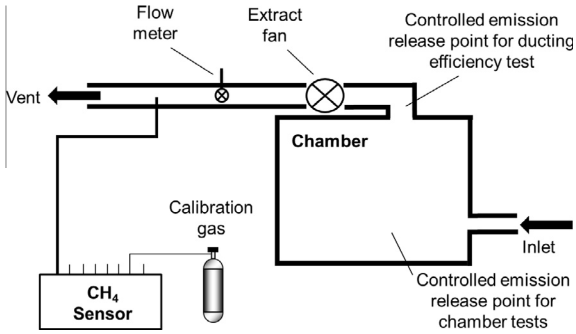

Fig. 1. Schematic of operational principle of livestock respiration chambers across six UK research facilities. Calibration gas and release points only included during National Physical Laboratory testing of facilities.

Incumbent facility staff were present in order to operate chambers, explain configuration differences and calculate the measured emission rates using their normal methods. However, all experiments were carried out by independent researchers from the National Physical Laboratory (NPL).

2.2. Calibration system design

A calibrated reference source of methane emission was produced by dynamically mixing ultra-high purity methane (BOC Gases, ⩾99.9995% purity) and nitrogen (Air Products BIP grade, <50 ppbv methane equivalents of hydrocarbon contamination) using an bespoke blender based on Aera FC-7000 series mass flow controllers (MFCs). The use of MFCs gives active control of the emitted flows, enabling stable flows to be maintained throughout the measurement periods. The blender system consisted of two pairs of MFCs. Each pair consisted of a MFC delivering methane and the other delivering nitrogen, with one pair set up for chambers usually measuring sheep and the other for chambers usually measuring cattle. The flows from the MFC pairs were set to provide an approximately constant total flow of gas independent of the amount of methane being delivered. Rather than relying on the manufacturers specifications, each MFC was directly calibrated for flow rate of the relevant gas via weight loss using NPL's gravimetric gas standard preparation facilities, which are recognised by the International Committee for Weights and Measures [14] as providing gaseous reference materials for calibration of UK laboratories to internationally validated levels of uncertainty [15]. This enabled mass emissions with an uncertainty of 1.0% (coverage factor of $k = 2$, 95% level of confidence – written as '$k = 2$, 95% confidence' hereafter) to be generated. The pair set up for sheep chambers were typically used to deliver 0.4 mg/s (~0.035 l/min) of methane in a total flow of ~1 l/min, while the pair set up for cattle chambers were typically used to deliver 6.0 mg/s (~0.5 l/min) of methane in a total flow of ~3 l/min. The outputs from the MFCs were combined using ¼″ stainless steel tubing and Swagelok fittings. The blender system was leak tested with soap solution prior to use and the line