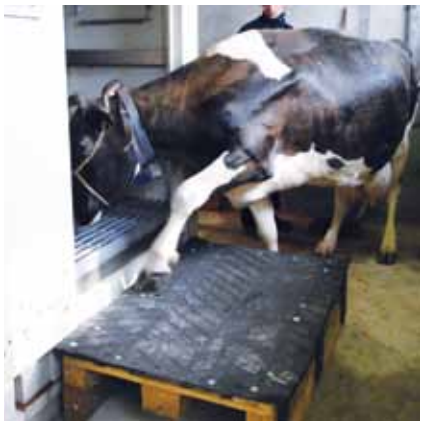
Technical Manual on Respiration Chamber Designs



February 2014

Edited by Cesar Pinares and Garry Waghorn

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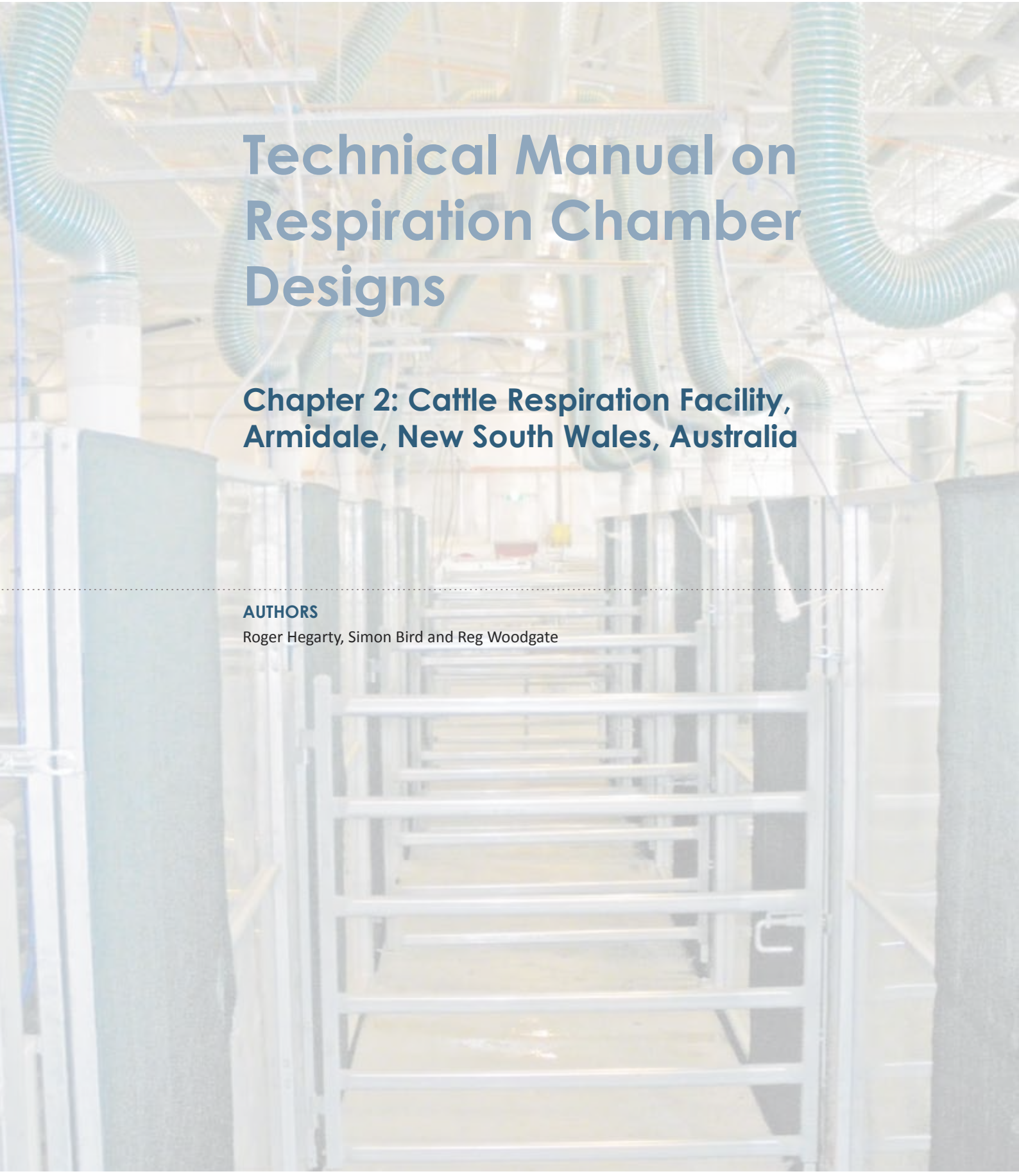

Technical Manual on Respiration Chamber Designs

Chapter 2: Cattle Respiration Facility, Armidale, New South Wales, Australia

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Contents

2.1 Summary

Ten open circuit respiration chambers have been constructed, initially for use in quantifying cattle methane production but will in future be used for energetics research. The chambers are of 20m^3 internal volume with an air flow rate of 1.6 m^3/min and consist of enclosed pens (1.8m x 3m) within a polycarbonate shell (3.6m x 2.4m x 2.4m). The chambers have no inbuilt floor but seal in a water trench recessed into the floor and are raised by pneumatics to allow hosing out of waste. Chamber air flow is measured by individual mass-flow meters and a continuous subsample of gas is drawn from immediately before each flow meter. Moisture is removed by a cold trap and a multiplexer used to direct dried sample air from each chamber and the ambient air into the analyser in turn. Methane, oxygen and carbon dioxide concentrations are measured over 10s after a 40s purge time by a Servomex analyser. Air flow and gas concentration data in the sampled air are loaded directly into a daily workbook with separate Excel spreadsheets for each chamber to allow gas production every 9 min to be determined. Methane recovery through chambers is measured by injection of a known dose of methane and integration of the peak area using first order kinetics.

2.2 Location of the facility

The physical address of the facility is:

University of New England
Trevenna Road, Armidale
NSW 2351, Australia

Mailing address:

Dept. Animal Science
University of New England
Armidale
NSW 2351, Australia

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The chambers are located in a new animal house facility in Armidale in northern New South Wales at 1000m altitude (Plate 1). This is on the campus of the University of New England and adjacent to existing animal house facilities for sheep studies (respiration chambers, metabolism cages, floor pens). The chambers are located inside a 48 m x 24 m concrete floored shed fitted with 36 individual cattle pens. The shed is insulated though not heated, and is well ventilated by roof vents and windows. Immediately outside the shed are four "Ruddweigh" self-feeders with data recorders for measurement of net feed intake. These feeders are formed on concrete bases but the surrounding pens are finished with compressed road-base (gravel) and a slope to ensure drainage. Cattle will be able to walk from the new facility to adjoining research farms by laneways in the near future. The "Tullimba" research feedlot (2000 head capacity) is 45 min drive away and trucks bringing cattle to the calorimeter facility can unload at the shed entrance, then cattle can be treated and weighed as required. A crush is located in the shed to facilitate weighing and taking of rumen, faecal and blood samples.

2.3 Description of the chambers structure

The ten chambers are arranged in two rows of five, with chamber doors opening onto a common aisle that runs between the 2 rows (Plate 2). The chambers are constructed of 75 mm hot dipped galvanised tubular steel modular frames to give length, width and heights of approximately 3.6 m, 2.4 and 2.4 m respectively, and an approximate volume of 20 m^3. The panels consist of roof, 2 sides, rear wall and front door with polycarbonate (3 mm or 6 mm) sheeting fitted to the inside of each panel. Joins between panels were sealed with silicone and panels bolted together on-site. The front door of the chamber is full width and opens into the aisle to allow cattle entry. Water is plumbed in for a drinker and a 120 L feed bin is provided on the front gate. The feed bin can only be removed by opening the chamber door.

Each chamber has made be raised or lowered into a matching 100 mm wide rebate into concrete floor which can be filled with water to provide a water seal (Plate 3.) and prevent gas loss when the chamber is lowered. Raising or lowering of chambers is achieved by 4 pneumatic rams, fitted one to each corner of the chamber and these are connected to a common compressed air line. The floor itself is painted with a 2 pack epoxy to prevent CO_2 absorption.

Bolted to the floor inside each chamber and 300mm in from the chamber frame, is a pen (3 m x 1.8 m) constructed of cattle panels which are bolted to the floor and for which a full width gate is positioned directly behind the front door of the chamber itself (Plate 4). The gate has a spring loaded catch for operator safety when cattle are being introduced. The permanent pen allows cattle to be enclosed without risk of damage to the polycarbonate chamber.

2.4 Animal holding, feeding and cleaning

Animals to be measured for methane production are adapted to diet for at least 14 d in the self-feeders outside of the shed. The quantity of feed loaded into the feed hopper each day is selected to provide the average intake required relative to maintenance for the total number of animals in the pen (max = 10). The feed intake data from these individual animals can be monitored electronically enabling any animals with variable or extreme intakes to be identified. In a typical measurement cycle, cattle are adapted to diet for 14 d on self-feeders in groups, then cattle are individually housed and fed a fixed ration for 2 d prior to entering the chambers for a further 2 d. A 2 day cleaning cycle is used throughout the shed. After 48 h in chambers, cattle are removed and sampled as required, then returned to the outside pen.

Plate 1: New Centre for Large-Animal Science Studies facility at UNE, Armidale.

Plate 2: Two rows of five chambers showing aisle between rows, overhead duct and droppers bringing fresh air into each chamber.

Plate 3: Pneumatic rams fitted one to each corner of the chamber, which lift the entire chamber from the water filled recess used to seal it. Lifting the chamber is initiated by a button on the chamber or automatically if the power fails or oxygen concentration decreases below 18%.

All chambers can be raised 20 cm above floor level (by compressed air pneumatics), to allow manure and urine from the chambers to be hosed across the shed into side trenches covered by grates. The next group of cattle that have been in individual pens are then moved into the chambers and the individual pens hosed clean in similar manner. A 2 m x 1 m rubber matt is located in the centre of each pen and chamber and the floor of the shed is sealed with a 2-part epoxy paint containing gravel aggregate to ensure cattle get adequate grip on the floor.

2.5 Chamber airflow piping and measurement

The respiration chamber air flow is reliant upon negative pressure in the system, achieved by high pressure fans placed at the exhaust of the system. A common stream of ambient air is drawn through a 30 cm circular galvanised iron duct from the outside of the shed (on eastern end) running above the mid line of the two rows of chambers. This duct is suspended from the roofing purlins of the shed and 10 x 150 mm diameter outlet droppers are positioned to provide the air intake above each chamber (Plate 2). From the duct to the chamber, a flexible (100 mm diameter x 2.5 m) steel reinforced flexible hose is used to connect to the top of the chamber, immediately above the feed bin and chamber entrance.

Inside the chamber, air is mixed by an oscillating fan (Plate 3) mounted on the roof at the rear of the chamber. On the roof behind the fan, a 100 mm outlet connected to the same type of flexible reinforced hose takes air from the chamber up 3 m to a 100 mm diameter PVC pipe running from directly above the chamber to directly above the analysis room. The length of PVC pipe varies from 22 m to 27 m reflecting the distance from that chamber to the analysis room. Above the analysis room, all PVC pipes are reduced to 50 mm (Plate 5) to thread directly onto a flow control manifold (Plate 6) composed of 10 mass flow meters fitted before individual gate valves which can regulate flow. Flow meters are from Fluid Components International, (Model ST75V). A sampling port to take 6 mm sample hose is tapped into each flow manifold immediately above the flow meter and a matching sample hose is connected to the air intake duct to provide a sample of ambient (incoming) air, giving 11 sample lines in total.

The common exhaust from the sample manifold is a 150 mm diameter PVC pipe that is connected by PVC pipe to the high flow fans that draw air through the systems. These are 2 x Aerovent HPE400 3-phase fans placed in parallel. One fan is fitted with a TECO Speecon 7200 inverter to provide variable speed control. The outflow from the two fans is combined and exhausted through the building roof.

2.6 Sampling, sample conditioning and analysis

Each of the 11 sample lines are connected to its own continuous flow pump drawing approximately 1 L of sample/min. These pumps are mounted above the refrigeration cabinet and pump (push) sampled air down through stainless steel coils contained in a refrigerator at 1–3°C (Plate 7). At the bottom of each cooling coil is a water trap to remove condensed water. The exit of each water trap is fitted with a non-return valve.

The 11 streams of dry air are pushed (using approx 3 m of 6 mm tubing) to the inlet ports of a sample multiplexer (Plate 8). In the multiplexer are two manifolds fitted with vacuum solenoids and in the closed position, the gas streams are vented from the multiplexer to waste. In this way, fresh air from each chamber is always passing through the multiplexer so there is only approximately 1 m of dead space to be purged between multiplexer and analyser for each analysis.

Plate 4: Inside of chamber (before protective film was removed from polycarbonate) showing internal pen that protects the chambers from damage by cattle. Also 40cm fan for internal air circulation. The chin closure system on the gate (visible) has since been replaced by a spring-loaded catch for operator safety.

Plate 5: Air ducting system from the 10 chambers is reduced from 10 cm o.d. to 5 cm o.d. at the point of entry in to the analysis laboratory and manifold. Exhaust is drawn to the high pressure fans by the 15 cm o.d. PVC pipe to rear.

Plate 6: Flow measurement manifold featuring 10 mass flow meters with digital output and gate valves to control flow.

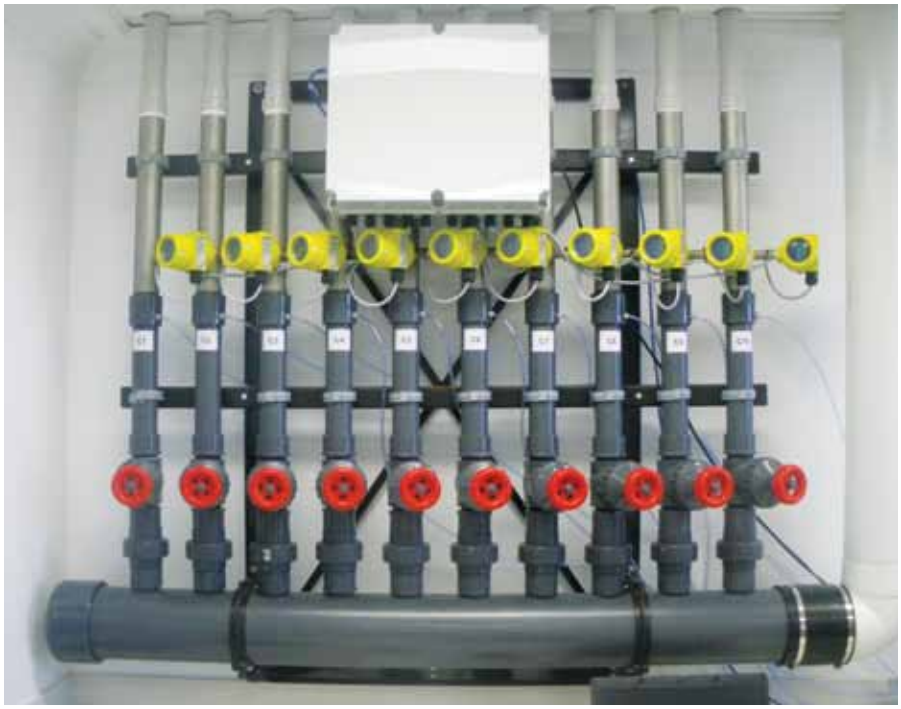


Plate 7: Sample drying system. Sample lines (10 sample + ambient) are drawn from the flow control manifold (Plate 6 above) at 1L/min by pumps mounted above the refrigerator (at top), which push the air through the refrigerated cooling coils which have autodrains of condensed moisture at the base.

The multiplexer is operated by a touch screen that allows any or all chambers to be included or excluded from sampling and to set the duration of sample purge and sample measurement. When the solenoid for a chamber (or the ambient line) is open, dried air from that sample line is directed to the sample outlet of the multiplexer (instead of the common vent) and 1 m of tubing connects the sample outlet to a pump (Vacuubrand ME1) which then draws 6 L/min from the flow manifold, through the 1 L/min pump, down through the refrigerated drier, through the multiplexer and pushes it into the flow control module. In so doing, this pump generates a pressure of 2 kPa that is tightly regulated in the flow control module (control valve is SMC, model KLF IBCA412A60000) after which 2 L/min is directed to a an outlet to connect to the CO_2 and CH_4 sensors in the analyser (in series), and 200 ml/min is directed to an outlet which will connect to the analyser's O_2 sensor.

The analyser itself is a Servomex model 4100C1 fitted with infrared detectors for methane (GFx1210. 500 ppm) and carbon dioxide (IR1520, 1% CO_2), and a paramagnetic sensor for oxygen (PM1158). These are spanned to apply the 4-20 mA signal between a low standard (0 ppm CH_4, 0 ppm CO_2, 16% O_2) and a high standard (98 ppm CH_4, 1010 ppm CO_2, 20.9% O_2). Calibration of the analyser is done daily for each gas using the mentioned standards, with the calibration gases being dispensed at 10 psi from the cylinder into the flow control module

2.7 Gas recovery test

Recovery of methane through the chamber system is quantified following a single injection of methane as follows. With the high pressure fans drawing air through the set of chambers, the air intake and exhaust pipes of a single chamber are temporarily sealed but the internal fan is left running. This circulates air within the chamber but no air is able to escape the chamber. A fixed volume of methane (1200 ml at ambient conditions) is injected near the internal mixing fan via a portal from outside and allowed to mix within the chamber for two minutes. After this time, the intake and exhaust pipes are opened to allow flow of air into and out of the chamber. The exhaust gas stream is sampled as occurs during routine operation, but sampling is every 50 seconds for approximately 20 minutes. Sampling time and methane concentration are recorded and the sampling time adjusted for the lag time between air leaving the chamber and arriving to the analyser (approximately 22 seconds). The methane concentration follows a logarithmic decline ($[CH_4]t = ae^{-kt)}$ so a linear regression can be fitted between the natural log of methane concentration verses the time of sample (r^2>0.99).

From this fit, three assessments can be made:

RECOVERY OF ADDED METHANE. From the regression, the total quantity of methane estimated to be present at the moment of methane injection can be calculated by multiplying area under the curve x the flow rate. This quantity is then expressed as a percentage of the known dose of methane injected. A failure to achieve acceptable recovery (98-102% of added CH_4) can occur due to errors in either methane measurement or flow rate measurement and these can be differentially diagnosed as below:

METHANE CONCENTRATION. By taking the antilog of the intercept from the linear regression, the concentration of methane in the chamber at the moment the exhaust and intake pipes were opened is estimated. This can be compared directly with the 'expected' methane concentration at this time, which is derived by dividing the methane injected (1200 ml) by the volume of the chamber (20,000 L). If the two do not match, then there is (a) a loss of methane from the sealed chamber or (b) some error in methane measurement as there is little error in the methane dose or the volume of the chamber which is based on measurement of its internal dimensions.

FLOW RATE. The linear regression provides a 'k' value or rate constant describing the decline in methane concentration, measured in terms of chamber volumes/minute. The theoretical k value (measured flow/min as shown on the mass flow meters divided by chamber volume) is calculated with adjustment for temperature and pressure (Data Harvest Group Ltd.) to a k vale for the ambient conditions of the day. If the theoretical and regression-derived k values differ, it identifies an error in the flow measured. This error could arise from leaks between the sample line and the flow meters (unlikely) or leaks into the sample line after the mass flow meter which allows air to dilute the sample. These leaks could be anywhere in the refrigeration drying unit, the multiplexer, flow control module or analyser plumbing. Sequential leak tests with nitrogen will be required to locate the leak.

2.8 Emissions calculation

Because the system relies on mass flow meters rather than dry gas meters, there is minimal data processing required. The 11 Excel spreadsheets capture sequential data (date, time, flow meter reading, and concentrations of three gases) in rows of a spreadsheet. An average gas concentration for each gas at each time is calculated. The concentration of gases in the ambient air stream at the start of that sampling cycle is removed. The values for net production/concentration of each gas over the period of study can simply be averaged and multiplied by the air flow over that time (final flow meter reading – starting flow meter reading). The output from this is gas production (or consumption) at normal temperature and conditions (0°C, 1.0 atmosphere pressure) that can then be converted to STP and so weight of methane produced.

Feed intake and DM content are recorded daily to enable emission to be reported as g methane and g methane/kg DM intake.

2.9 Animal welfare and operators' safety

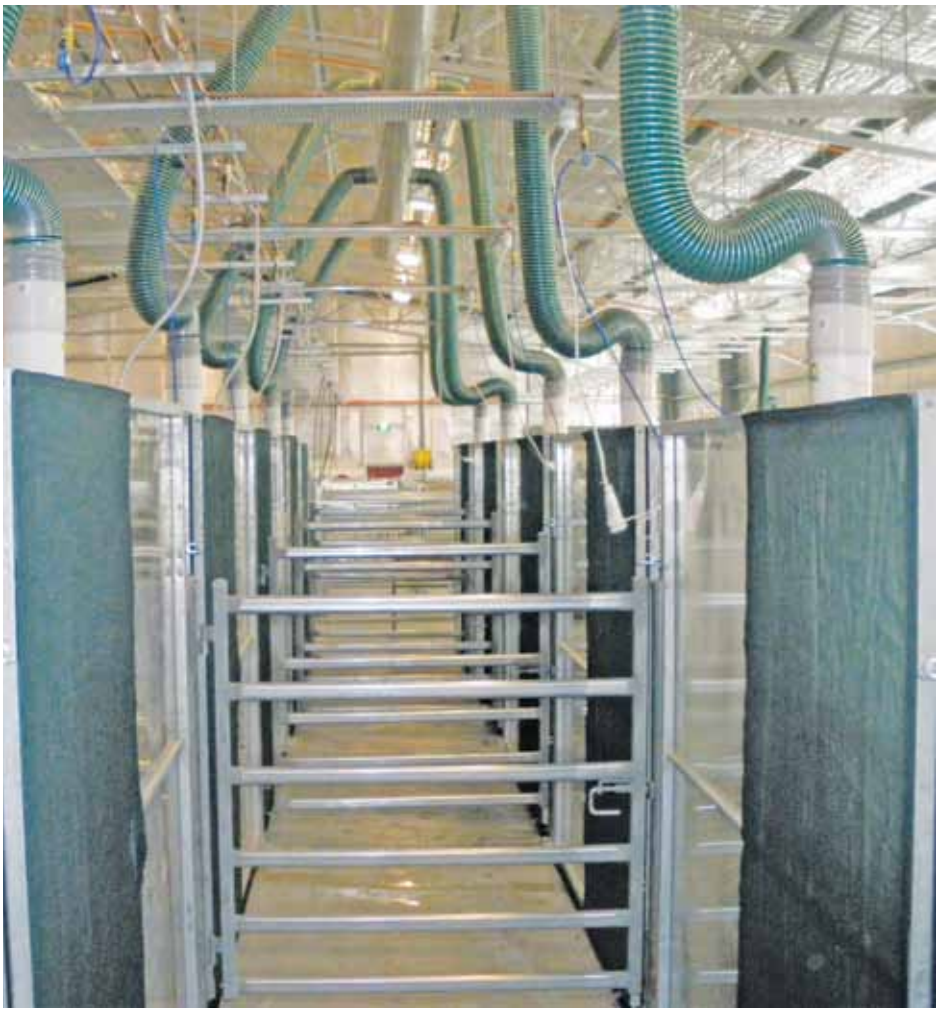
Operator safety

The chambers are designed to allow cattle to be walked into them, with safety of the operator being paramount. Two handlers are always present to move cattle. This is achieved by:

- A panel walkway linking the cattle crush/handling facility to the aisle between the two rows of chambers, and a separate return walkway back to the crush area (Plate 2).
- For getting animals into chambers, the chamber door (framed polycarbonate) and pen gate to one of the furthermost chambers is opened so the animal can only enter the chamber or return the way it has come. A hook on a cord is attached to the open pen gate so that the gate can be pulled shut from further up the aisle way. As the animal proceeds down the aisle, a series of gates with snap-lock fasteners can be shut behind it by the operator who follows on foot, preventing the animal's return (Plate 9).
- Once the animal is in the pen, the nearest aisle gate is shut and the chamber gate pulled closed by the hook and cord so that the spring-loaded chamber gate latch secures the animal in the chamber pen.
- The polycarbonate chamber door is then closed using two industrial snap latches.
- The door and gate on the opposite chamber are then opened and that chamber filled in like manner.

Plate 8: Gas handling and analysis system. The 11 dried sample streams are continuously pushed (1 L/min) through the gas multiplexer (bottom) which features a touchpad allowing the desired number of chambers to be selected for sampling, as well as their purge time and measurement time. Solenoid valves within the multiplexer allow one gas stream to be open for analysis, which involves sucking that sample (at 6 L/min) through the flow control module (middle box) which regulates pressure and creates differential flow to the 3 detectors. The individual sample flows are then directed to each detector in the Servomex 4100 analyser.

Plate 9: Aisle between chambers shown with all gates shut. These gates are all open to start and the door to the most distant chamber is opened. As cattle walk down the aisle, the gates shown can be progressively closed to ensure the animal does not come back to harm the operator following it down to the chamber. The individual sample flows are then directed to each detector in the Servomex 4100 analyser.



Animal welfare

The primary risk is asphyxiation in the event that air flow through the chambers stops (power blackout or fan fault), and this risk has been minimised by:

- Use of two high pressure air fans in parallel, so that failure of one fan will not stop air flow.
- Automatic lift of the chambers 20 cm above floor by pneumatic rams (as for cleaning) in the event of power failure or oxygen concentration falling below 18% in the chamber.

2.10 Weaknesses of the system

The system is new and has much scope for improvement for ease of operation. Key improvements anticipated are:

FLOORING IN CHAMBERS AND PENS. At present the cattle are standing on rubber mats and so become surrounded by their own excreta over time. We intend to put raised floors for the cattle to stand on for welfare reasons but also to facilitate hosing out.

TEMPERATURE AND HUMIDITY CONTROL. Currently there is no temperature or humidity control in the chambers. This needs to be established before energetic studies can be entered into. We are anticipating this will be individual air conditioning units on each chamber.

DATA MANAGEMENT. While functional, the data collection and processing software is still requiring considerable manual processing. We hope to get this automated quickly and will work with the designer to do so.

2.11 Description of components and equipment suppliers

Pen design, construction	Local contractors
Chamber design and construction	UNE Sciences workshop
Air ducting system and fans	Selves with local contractor
Mass flow, and all analysis hardware	AZCO holdings, Auckland NZ
Data handling software	AZCO holdings, Auckland NZ

2.12 Costing of the facility complete system with ancillary equipment

ITEMS	US$
LABOUR	
Design of the system	In house
Cattle pens within chambers (10)	15,000
Building of chambers	80,000 includes materials
Piping air circulation and sample lines	33,000 includes materials
Wiring, data acquisition, software development	Included in equipment cost
Monitoring and commissioning	Included in equipment cost
Tests	4 weeks
MATERIALS	
Building materials	In labour
Pipes, cables, etc	In labour
EQUIPMENT	
Minor assets (sensors, pumps, etc)	2,000
Mass flow meters (10)	34,000
Gas analyser	29,000 (CH4, CO2,O2)
Sample drying system	34,000
Gas switching system	Included in dryer cost
Calibration gases	3,000
Computer and data acquisition system	6,000
TOTAL COST	**236,000**