A RESPIRATION CHAMBER FOR CATTLE

H. G. TURNER* and R. F. THORNTON*

Summary

A chamber is described in which the "confinement" principle of measuring gas exchange is utilized. The system is completely sealed during a run lasting about one hour and its oxygen content (or carbon dioxide or methane content) is recorded and plotted against time. The determination has high precision and is immediately responsive to temporal changes in gas exchange.

I. INTRODUCTION

Traditional methods for measurement of gas exchange in domestic animals utilize the open-circuit principle in which a known flow of air is drawn past the animal and its change in composition is measured; or the closed-circuit principle in which carbon dioxide is absorbed and weighed and oxygen is metered into the system. The open-circuit chamber has an exact counterpart in a mask method and the closed-circuit chamber an approximate counterpart in a mask-spirometer method. A third principle in which the system is completely closed and there is no oxygen inflow or carbon dioxide absorption, but in which change in air composition is measured, was used for pigs by Charlet-Lery (1958). This "confinement" principle has been adopted by us for application to cattle.

Design of the unit embraces:

(a) A cage to hold the animal.
(b) A completely sealed chamber.
(c) Air conditioning to control temperature and humidity.
(d) Instrumentation to provide a continuous record of parameters needed for a plot against time of the oxygen (or carbon dioxide or methane) at S.T.P. in the system.

II. DESIGN AND CONSTRUCTION

A prototype chamber of sheet steel and channel iron with many of the ancillary fittings built as part of the chamber was discarded as cumbersome and subject to leaks. Two fibre-glass chambers have been built and the second of these, differing from the first only in dimensions and minor details, will be described. The unit is illustrated diagrammatically in Figure 1 and pictured in Figure 2.

(a) The Chamber

The chamber is 9 ft (2.75 m) long 3 ft 6 in (1.07 m) wide, and 6 ft (1.83 m) high, constructed as an integral unit with the bottom side open. The

*Division of Animal Genetics, C.S.I.R.O., Cattle Research Laboratory, Rockhampton, Queensland.

fibre-glass, $\frac{1}{8}$ in. (3 mm) thick, was cast on a timber mould, and 1 in. x $\frac{1}{2}$ in. (25 x 12 mm) channel iron was bonded into the resin to strengthen edges and faces. The internal surface is therefore smooth and the framework projects externally. The fibre-glass is translucent and supplements illumination from the two "Perspex" windows. The chamber weighs about 300 lb (140 kg) and can be quickly raised clear of the cage or lowered into the moat which provides a water seal (Figure 1).

(b) The Cage

The cage is a fairly neat fit inside the chamber walls and is 5 ft (1.5 m) high, leaving 12 in. (30 cm) between top of cage and roof of chamber. It is a framework of 1 in. (25 mm) pipe covered internally with 3 in. (7.5 cm) steel

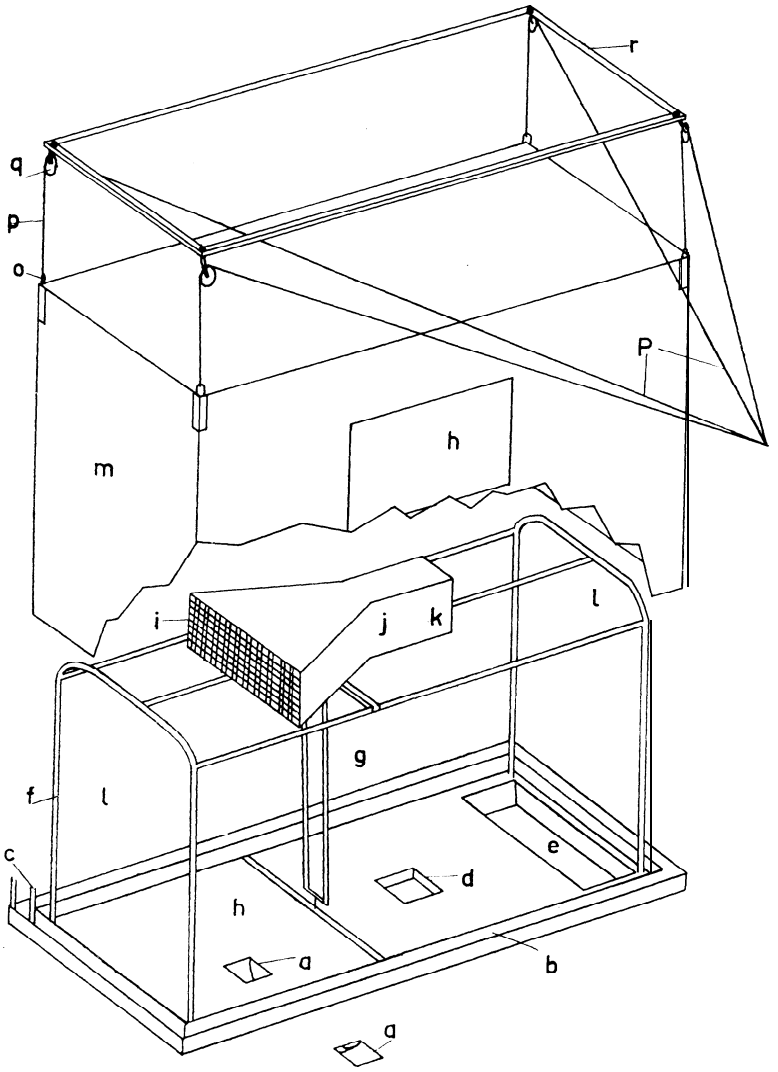

Fig. 1.—Schematic diagram of chamber and cage.

mesh. An entry door is at the back and there are small access doors at the front and on each side. The cage incorporates an adjustable yoke, and feed and water bins which can be covered and uncovered by external control.

(c) Air Conditioning

A 3 H.P. refrigeration unit, remote from the chambers, provides a reservoir of cold water which is circulated via insulated 1 in. (25 mm) piping through a coil mounted on the roof of the cage. A duct leading from the coil contains a three speed exhaust fan and heating coils of which the power output can be varied. The heaters are controlled by a bimetal thermostat and hot-wire vacuum switch. Dry-bulb temperature is thus controlled automatically and humidity may be controlled within limits by adjusting refrigerant temperature or flow, fan speed and degree of reheating. Ancillary fans ensure thorough mixing of chamber air. Wet and dry bulb thermocouples are placed in various positions in the chamber and records from them confirm thorough mixing.

(d) Gas Analysis

Air is pumped continuously from the chamber, through a small sampling circuit which incorporates dust trap, solenoid valves and relief valve, and back to the chamber. These circuits from both chambers operate continuously, and a manifold, with solenoid valves, provides for each in turn to be diverted through the analyser circuit. The analyser circuit is kept to a minimum of dead space. The whole system involving chamber, floor and sampling circuit is made air-tight. This is tested by maintenance of positive or negative pressure and any leaks are located with the aid of Freon 12.

The analyser circuit incorporates a Beckman Paramagnetic Oxygen Analyser Model F3M2, and provision has been made for incorporation of two Beckman

---

Legend Fig. 1.

a: Acces duct, 6″ (15cm) square, water-sealed, for entry of pipes and leads.
b: Moat 6″ (15 cm) deep, 4″ (10 cm) wide, made of steel and sealed into concrete with pitch.
c: Pipe to provide air bleed for equilibration of chamber before sealing.
d: Urine sump (urine pumped to container on top of cage).
e: Pit for faeces tin.
f: Cage.
g: Adjustable yoke.
h: Position of feed and water bins.
i: Cooling coil, 30″ (76 cm) x 10″ (25 cm), double-banked.
j: Position of 3-speed, 10″ (25 cm), exhaust fan in duct.
k: Position of heaters in duct.
l: Positions of additional mixing fans.
m: Chamber.
n: "Perspex" window, 3' x 2' (0.9 x 0.6 m) (one in each side).
o: Steel rings bonded into chamber.
p: Wire ropes.
q: Caster pulleys.
r: Fixed overhead steel frame.

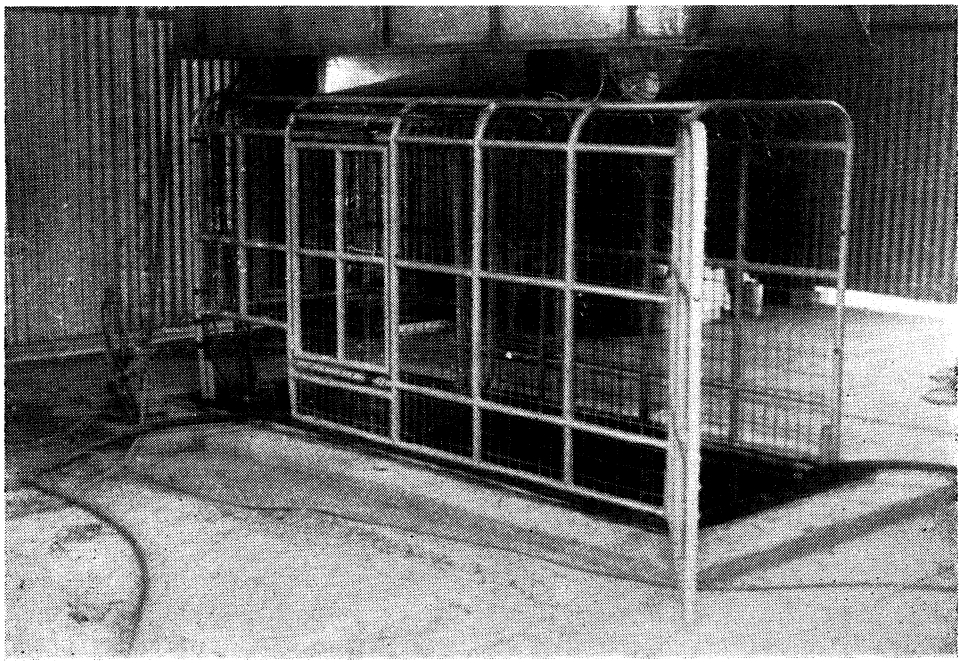

Fig. 2a.—Cage with chamber elevated.

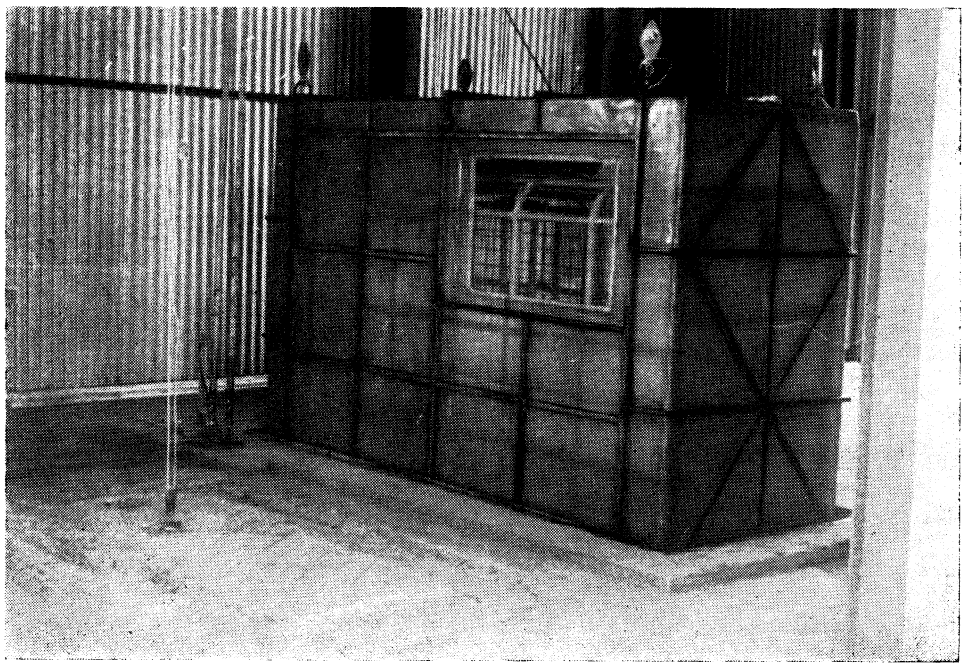

Fig. 2b.—Chamber in position.

Infra-red Analysers in parallel to provide records of carbon dioxide and methane production.

A pressure transducer ("Ether" Type UP 2, J. Langham Thompson) is used to record any difference between barometric pressures inside and outside the chamber. Barometric pressure is at present read manually when required from a sensitive aneroid barometer (Mechanism Ltd., U.K.).

The various parameters are recorded on two 12-channel potentiometric recorders (Speedomax G), one with range O-5 mV and the other O-l or l-2 mV. One recorder has a harness which switches solenoids for air flow and for the pressure transducer synchronously with selected channels.

III. OPERATION

In a single run, oxygen content is allowed to decline to 19 % and this is accompanied by a rise in carbon dioxide to about 1.5-2%. Neither of these changes has significant physiological effect (Blaxter 1962). This limit determines duration of the run which varies from about 30 to 100 minutes according to size and state of the animal. Air can be quickly renewed for recommencement of a succeeding run.

Oxygen consumption is determined as the change in oxygen content of the system. If chamber air is circulated to the Analyzer unchanged, then the volume of oxygen at S.T.P. at any time equals:

$$273\ (V_1 \pm V_2 - V_3)\ P\ /\ (760\ T)$$

where V_1 = volume of the system (1.)
V_2 = a small correction for effect of any pressure differential on chamber volume (1.)
V_3 = volume of the animal (1.) = weight (kg) $\times$ specific volume (I./kg)
P = partial pressure of oxygen (mm Hg)
T = dry bulb temperature (°K)

The oxygen Analyzer senses partial pressure of oxygen and it is more useful to calibrate its scale in these terms rather than transform it to percentage by volume. Adopting this principle, changes in barometric pressure or vapour pressure are irrelevant to the measurement required, and the expression remains quite simple.

Absolute accuracy has not been assessed and not all components of precision have been examined, but a likely perspective of errors arising from the various terms in the foregoing equation is given in Table 1. Firstly, this shows that an uncontrollable source of error, specific volume of the animal, has a negligible effect on precision, whereas temperature, the precision of which could be improved, accounts for nearly half the total error. Error within a run, determined in actual trials from the standard error of regressions of oxygen content on time, corresponds closely with that shown in Table 1. As the determined error includes any biological variation in oxygen consumption during a run, and technical error yet to be improved, it appears that instrumental error is if anything overestimated in Table 1. The error within a run, shown as the error of the difference in oxygen content between two points, can be reduced, though not dramatically, by

TABLE 1

Assessment of errors of measurement in determinations of oxygen consumption

Measurement	Mean	Standard Deviation	Coefficient of Variation	Contribution to Net Variance %
(*a*) *Errors within a run*:				
Chamber Vol. (l.)	5200	2	0.04	2 x 9.5*
Vol. of Animal (l.)	285	0	0	0
†Partial Pressure of 0_2 (mm Hg)	150	0.03	0.02	2 x 2.4*
Temperature (°K)	300	0.2	0.07	2 x 24.8*
Vol. of 0_2 at STP in system (l.)	883	0.7	0.08	2 x 36.7*
0_2 Consumption (l.)	88	1.0	1.13	73.4
(*b*) *Extra component of error between different runs with different animals*:				
Chamber Vol. (l.)	5200	5	0.1	0.6
Animal weight (kg)	300	2	0.04‡	0.1
Specific Vol. of animal (l./kg)	0.95	0.015	0.09‡	0.5
†Partial pressure of 0_2 (mm Hg)	15	0.10	0.67	25.4
Temperautre (°K)	300	0	0	0
0_2 Consumption (l.)	88	0.6	0.68	26.6
(*c*) *Total error of measurement* (*a* + *b*):				
0_2 Consumption (l.)	88	1.17	1.32	100

*0_2 Consumption as shown here is determined as difference in 0, content of system at two points in time. Then error variance of 0, consumption = twice error variance of 0_2 content.

†Precision of partial pressure is affected by sensitivity only under (a), and under (b) by span calibration and zero drift during a run.

‡Expressed as percentage effect of the deviation on net air volume of 4915 l.

calculation of a regression from several points. Nine equally spaced points (though fewer extreme points) are needed during an interval to make the error of oxygen consumption in litres per interval equal to the error of oxygen content of the system in litres.

It appears that the potential net instrumental precision, allowing for differences that may occur between widely separated runs with different animals, is if anything less than 1.17 1. per interval, equivalent to 1.3 % of the rate of oxygen consumption determined during a complete run. If 16 such determinations were made, say in a period of 24 hours, error of their sum or mean would be reduced by a factor of $1/\sqrt{16}$ i.e. to 0.3%.

At present, the reading of oxygen pressure is not independent of humidity, apparently because of absorption and release of water in the sample circuit. Until this is corrected, silica gel traps have been incorporated in the sample circuit, and the calculation of oxygen volume becomes:

$$273\ (B - H)\ (V_1 \pm V_2 - V_3)\ P\ /\ (760\ T.B.)$$

where B = barometric pressure in the chamber (mm Hg)
H = vapour pressure in the chamber (mm Hg)

This expression entails recording of extra variables, and extra sources of error.

IV. FEATURES OF THE METHOD

(a) Advantages

(i) Although it includes some expensive instrumentation, the equipment is otherwise simple and economical to construct and operate.

(ii) Precision is high and compares favourably with other methods. A precise measurement of gas exchange can be obtained in a short time and determinations can be extended or replicated as desired.

(iii) Measurement of gas exchange is direct and immediate. The unique feature of the method in comparison with other chamber methods is that exchange is measured, without lag, within a few minutes of starting a run and any changes during a run are recorded. A reaction to treatment, e.g. presentation of feed, is detected in less than two minutes (Vercoe and Thornton, unpublished data).

(iv) The system could be readily converted to the open-circuit principle if desired.

(b) Disadvantages

(i) Total exchange over a long period cannot be measured directly but is estimated by summation of periods between which there are short interruptions for renewal of air.

(ii) The chamber is normally run at atmospheric conditions near ambient. Because of the need to renew air, special adaptation would be needed to maintain chronic exposure to conditions other than ambient.

(iii) Without more elaborate automation, presence of an operator is required at change-over of runs.

V. ACKNOWLEDGMENTS

Dr. G. C. Ashton played an important part in early stages of development, especially in instrumentation. Dr. J. E. Vercoe has contributed latterly in calibration and testing. Mr. J. F. Kennedy and his staff at the National Cattle Breeding Station have helped in many aspects of construction, and Mr. J. T. MacKenzie has rendered devoted technical assistance.

VI. REFERENCES

CHARLET-LERY, G. (1958). Méthode de measure de courte durée des échanges gaseux. In: 1st Symposium on Energy Metabolism. pp. 194-202. European Association for Animal Production, Rome. Publication No. 8.

BLAXTER, K. L. (1962). "The Energy Metabolism of Ruminants". (Hutchinson: London).