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Technical note: A wireless telemetric method of monitoring clinical acidosis in dairy cows

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ABSTRACT

Ruminant animals convert forage containing cellulose by bacterial fermentation into nutrients. The health of the bacterial culture in the rumen is essential for the health and productivity of the animal. Over a number of years fistulated animals have been used to study the rumen and its bacterial population. It has been shown that techniques to maintain the pH of the rumen between 7 and 5.5 pH are essential for the health of the dairy cow. The rumen pH has been recorded by using sensors suspended in the rumen at intervals or exceptionally with data recorders. However, fistulation of an animal requires surgery and is only suitable for a few research animals. This paper describes the development of a telemetric bolus that measured and recorded pH continuously. When interrogated by wireless the bolus transmitted the recorded data to an operator standing beside the cow with a receiving station. Boluses were placed in fistulated animals so that a comparison could be made with a laboratory instrument. Data are presented that show a close correlation between the calibrated laboratory instrument and the bolus at time intervals when the instrument was inserted. From this it can be assumed that the bolus accurately records the temporal variation in rumen pH. Data are presented to show the diurnal change in rumen pH over a 6-week period. Methods of increasing the lifetime and accuracy of the bolus are discussed.

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1. Introduction

The pH of the rumen of dairy cows is controlled by a number of processes to maintain a population of bacteria capable of digesting a fibrous bulk diet. Various research techniques have been developed to enable some understanding of this complex anaerobic environment. However, routine frequent measurements have long been known to be desirable but until the technology revealed in this paper the rumen was a remote environment about whose status we could only extrapolate between rarely sampled data points in fistulated animals on research farms.

The efficiency of the bovine digestive system is dependent upon the acidity of the rumen being maintained within a range ≥5.8 pH by ensuring an adequate balance of nutrients and fibre for the rumen flora. Various dietary characteristics can affect the pH value of the digestive system, and a number of diseases may affect the pH within the rumen. The measurement of ionic activity has been employed to monitor the rumen status of bovines, particularly to detect sub-acute rumen acidosis (SARA) which is defined as extended periods below 5.5 pH. Until this product rumen acidosis could only be detected by surgical procedures such as lumbar puncture or fistulation of the animal (Garrett et al., 1999) other authors used a permanent surgical modification with an external datalogger or radio link (Mehrota, 2002; Nocek et al., 2002). Peters (1997) described a novel pH sensor with a free-flowing junction to compensate for pressure changes used to detect digestive processes

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in penguins. However, none of the devices previously disclosed offered a simple, accurate long lasting measurement of pH in unmodified cattle.

The problem is not impossible as the autonomous pH probe, developed for humans (Medtronic product literature) is widely used. Probes of this type employ "gastric telemetry" to transmit data detected by a sensor in the probe via radio signals. The main difference is that because the rumen has a unique ability to trap and retain suitably weighted objects a device can remain resident in the cow transmitting accurate pH recording for several weeks. However, anecdotal evidence suggests that attempts to maintain a rumen pH for more than few days have failed due to sensor drift. The objective of this study was to develop and demonstrate a bolus sensor that could maintain accurate measurement of rumen pH (±0.2 pH units) for in excess of 42 days.

2. Materials and methods

The bolus consists of a sensor, an electronics component to transduce and condition the signal and store the data, a radio transceiver, aerial and battery all sealed within an enclosed container small enough to pass down the throat of an animal.

The sensor is a pH sensor (see Fig. 1) with the reference cell being a gel-filled annular space around a glass electrode bulb and the reference junction being porous Teflon. A pH electrode can be compared to a battery in that an electrical voltage is generated between two points that is a function of water

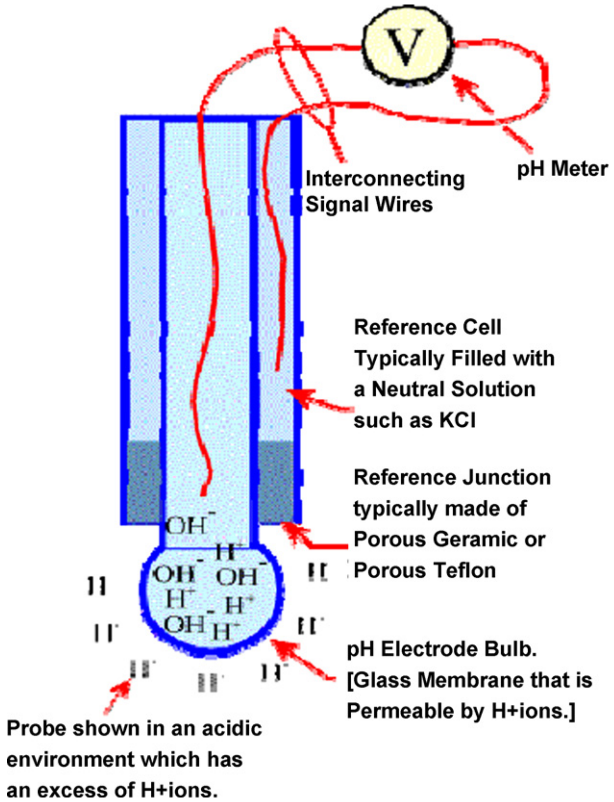

Fig. 1 – Schematic of a laboratory pH sensor, the Well Cow system replaces the pH meter with a microprocessor and radio link to make the device self-contained.

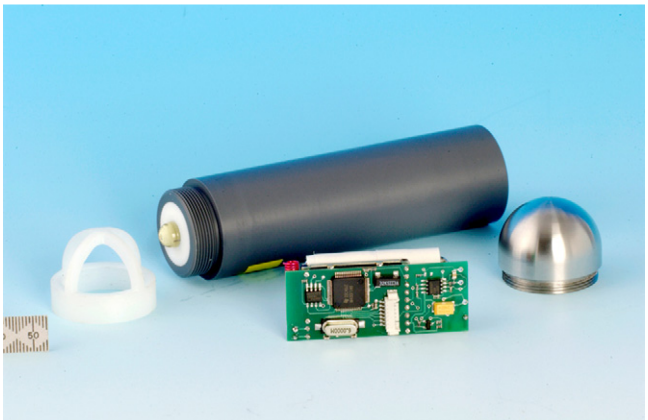

Fig. 2 – Disassembled bolus, in use the system is sealed.

chemistry. In the case of a pH electrode the voltage potential is a function of the acidity or alkalinity of the solution in which it is immersed.

The pH element is a thin glass membrane that is permeable by H+ ions. The electrode is filled with a neutral solution, which by definition contains an equal number of H^+ and OH^- ions. When the probe is immersed in an H^+ rich environment (acidic) the glass membrane is permeated by the H^+ ions which exert a positive potential on the sensing electrode. This potential difference is measured by a pH meter and converted to a pH output.

Likewise, when the probe is immersed in an alkaline environment there exists within the probe a higher H^+ concentration than outside of the probe. This causes H^+ ions within the probe to migrate outside of the probe which leaves an excess of OH^- ions within the probe. A negative potential is thus sensed by the pH meter.

The pH electrode depicted is a single junction glass bulb electrode which is the most commonly used pH electrode in industry. There are many other variations including double junction, antimony and specifically formulated glass for various environments. In normal use the effects of using the pH electrode in materials that differ from neutral for long periods cause the sensor to become poisoned and this is overcome by recalibration. Inside the rumen this is not possible and so design features (which may be disclosed after a patent application) have been used to slow down the effects of electrode poisoning. Probes for pH measurement are inherently unstable and normally require frequent cleaning and calibrating. However, the glass formulation and reference junction of this invention have been designed to be stable for at least 60 days.

The main bi-directional communication link between the bolus and the hand-held data collection unit currently operates on a frequency of 433.92 MHz. The output power of the hand-held unit is 4 mW into a quarter-wave whip. The bolus itself has similar output power, but into a less-efficient antenna. The system is in accordance with European (ETSI) "Industrial, Scientific, and Medical" (ISM) standard EN-300-220-3 and is thus license-free in all European (ETSI) countries.

A bolus (see Figs. 2 and 3) is completed when it is sealed up and completed and the electronics and battery begins to

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Fig. 3 – Bolus equipment set comprising radio handset for computer attachment, bolling gun and six boluses.

operate from this date. The identity of the bolus is individual and it is programmed to only respond when its unique identity is interrogated. After the sensor is calibrated and calibration constants are entered into the bolus microprocessor by software the bolus is placed in the animal by mouth. An identity tag is placed in the animal's ear or checked if it already exists. Subsequently when data is required the operator approaches the animal. The identity of the animal under test is read and the identity of the bolus entered into the software. The relevant bolus is then interrogated by the communication system so that only data from the relevant bolus is obtained. The signal from the animal is non-linear and appears to spread in a fan-shaped area down and behind the animal. Along the lower rib cage the antenna has to be within 100 mm of the skin but in the vicinity of the udder good signals were obtained as much as 2 m laterally 0.5 m above the floor.

The boluses were inserted into the rumens of four fistulated steers on a dietary trial. At intervals (minimum 1 h) a sample of rumen liquor was extracted from the vicinity of the bolus and measured immediately with a recently calibrated pH meter inserted via the fistula and the diet recorded. The steers were on an experimental diet to simulate extensive grazing during drought conditions. Feed was periodically

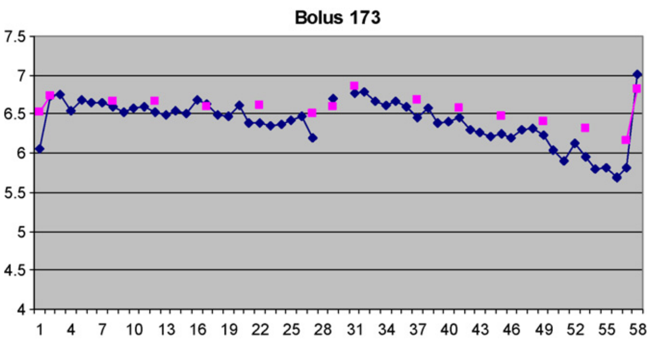

Fig. 4 – Record of bolus and reference pH data over a 14-h period, vertical axis is pH, horizontal axis is the number of automatic samples at 15 min intervals. Squares are manual readings at approximately hourly intervals via fistula, diamonds are the pH telemetry bolus.

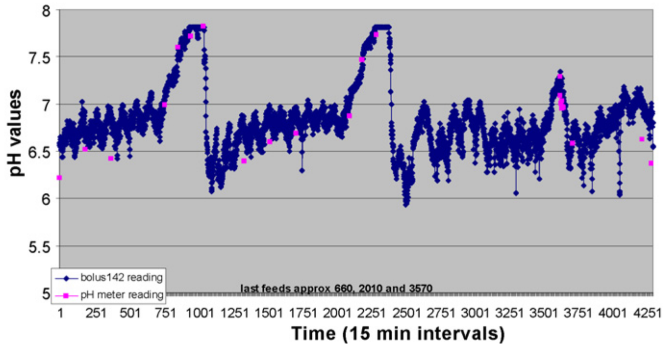

Fig. 5 – Bolus 142 data over a 44-day period compared with reference. The normal daily fluctuation in pH is clear—1–750 = 1 week, followed by a fasting period then a drop following a feed then a return to a normal daily cycle over 10 days then a repeat of the pattern. This graph highlights the different detail of analysis that the novel technology permits.

offered and withdrawn. After four days the data from the bolus were downloaded and compared against the reference probe.

3. Results and discussion

The principal difference between the bolus system and traditional pH meters deployed by fistula is the ease and simplicity with which large amounts of data can be collected from a difficult and easily perturbed location. For all practical purposes a rumen bolus is unrecoverable for recalibration or servicing until post-mortem. The purpose of our current development programme is to establish baseline data on the bolus with fistulated animals where we can compare performance and recalibrate and service the bolus. In the long term when calibrations are well established we will be confident in using boluses for extended periods in unmodified cattle.

Even when inserted by fistula the bolus migrated to the rumen reticulum within a few hours of insertion. In some tests this could probably be identified by a slight change in pH. It is well known that the compartmented stomachs of the cow have pH gradients as the rumen flora digest the various dietary constituents in a churning mass of fibrous material. In this study the extraction of rumen liquor was as close as possible to the bolus thus removing some of the offset due to location. However, the rumen is dynamic and non-homogeneous and there is no guarantee that the same fluid was being measured given the inertia of pH sensors and that that the placement is entirely tactile at extreme arms length. The bolus is reading inherently more data as the a/d is sampled every minute and the average over 15 min is calculated and this compares with a meter reading which is transient. A truer test would be an anchored pH meter tied to a bolus, however, that is a non-practical and probably unnecessary experiment.

The radio download of data took a few seconds and presented no major problems. The emission field around the cow was highly variable and non-linear. It offers an opportunity for further research to determine the optimum location and

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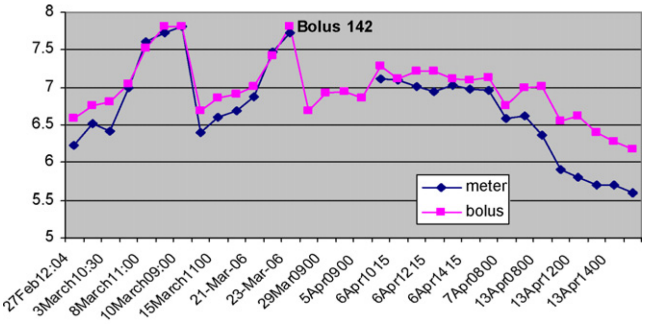

Fig. 6 – Rolling mean of pH bolus 142 compared to reference, vertical axis pH units.

configuration of antennae both within the bolus, where space is a major issue, or outside the cow where it is not.

In one test the bolus 173 was compared at intervals of approximately 1 h with a reference probe (Fig. 4). The graphs match well in profile with a slight under reading by the bolus. When the pH begins to change rapidly the bolus can read many more points.

The difference in data generated is even more emphasised in Fig. 5 which was recorded over 44 days. The reference probe completely misses large fluctuations in rumen pH. These have a daily cycle even in these animals on a restricted diet. When the animals are given a grain feed the pH rises rapidly and then falls sharply presumably as the rumen flora adapt to a sudden new source of nutrients.

The aim of future work is to reduce the drift that occurs due to a poisoning of the electrode over time. This can be seen in Fig. 6 where a rolling mean for the bolus is compared to the reference electrode. For most of the period there is approximate agreement (±0.2 pH units) between the two but after about 35 days the difference increases. This presents a major challenge for future work. There is also a major opportunity to add other sensors to the basic platform.

At this stage with only a few boluses built and tested it is possible to show that the authors have demonstrated a novel technology platform which will have major implications for research in cattle diets in the future.

Acknowledgements

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