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Use of Wireless Rumen Sensors in Ruminant Nutrition Research

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ABSTRACT

This study discusses future trend and advantages of wireless rumen sensor (bolus) technology in ruminant nutrition research and obstacles that prevent their fast adoption. Wireless rumen sensors used in animal management and enrolment procedures but the technology is still at its early development stage in ruminant nutrition research. Rumen sensors provide an excellent and affordable option for continually measuring *in vivo* pH, temperature and pressure and offer scientists the ability to discover new insights into nutritional research, animal health and behavior, animal welfare, estrus, motility and morbidity dynamics, animal emissions, activity and digestion etc. under different ruminal conditions. This technology is easy to use, user-configurable and adaptable to most research programmes. Data is received and interpreted by the proprietary software via cable connection, wireless connection, bluetooth or manual download from memory card. New developments enable to obtain complete, comprehensive and accurate data sets from the rumen of animals at anytime, whether they are in free stalls, open paddocks or out on the range. The technology has a very good application for ruminant research, especially in rumen fistulated cattle and sheep. In some studies pH readings from boluses to that of a hand-held pH meter and found that there was a high degree of agreement between the two techniques. On the contrary, in other studies resulted in a minor level of agreement between the two methods. In conclusion, these boluses need further advancement to be potentially used for continuous rumen pH measurements for research purposes. It is expected that the rumen sensors can be measure rumen volatile fatty acids and greenhouse gases as CH_4, CO_2, NH_3 in the future. Therefore, animal nutrition studies can be commented more easily and also the most suitable feeding programme can be practiced.

Key words: Rumen sensor, bolus, ruminant nutrition research, wireless technology

INTRODUCTION

Wireless sensor technologies have rapidly developed during recent years. Deployment of wireless sensors and sensor networks in agriculture and food industry is still at early stage. Applications can be divided into 5 categories:

- Environmental monitoring
- Precision agriculture
- Machine and process control
- Building and facility automation
- Traceability systems (Wang *et al*., 2006)

Other areas exist where these technologies are used. Wireless sensors have been used in agricultural sectors to assist in spatial data collection, precision irrigation, variable-rate technology and supplying data to farmers. Besides, wireless sensors have been used in agricultural facilities, such as greenhouses and animal-feeding facilities. Monitoring climate-related variables within an animal house can be a helpful tool to monitor animal health. Wang *et al.* (2006) reported that some researchers developed a portable, mobile instrument to measure temperature, relative humidity, noise, brightness and ammonia content in the air within the house and transferred the data wirelessly to a PC through an infrared data link.

There are reports on the application of wireless rumen sensor technology to ruminant monitoring. By monitoring and understanding individual and herd behavior of ruminants, farmers can potentially identify the onset of illness, lameness or other conditions which might allow early intervention. Low cost sensor network platforms show considerable potential in this context but face a number of significant technical challenges before they are widely and routinely adopted (Kwong *et al.*, 2008).

In recent years, wireless sensors (rumen sensors or bolus) have been adopted in animal nutrition studies. This study provides an overview on recent development of wireless rumen sensor technologies in ruminant nutrition research. The study also discusses advantages of wireless rumen sensors and obstacles that prevent their fast adoption in animal research.

Wireless rumen sensors in ruminant research: Rumen sensors, which are used in scientific studies despite the fact that they are not common presently, reside in the raft/mat of the rumen and measure ruminal dynamics continuously. The current rumen sensors commonly measure temperature, pressure/motility and pH. The technology is easy to use, user-configurable and adaptable to most research programmes. The bolus provides a potential to improve the understanding of rumen dynamics. The technology is a very good tool in ruminant research, especially in rumen fistulated cattle, goat and sheep. The technology would strongly recommend its use to others. Wireless rumen sensors can overcome the logistical difficulties and sometimes biased methods of collecting rumen measurements.

We can conclude that there are a lot of sensors which have been developed by different companies and research centres. The most known and widely used wireless rumen sensors in ruminant nutrition research is Kahne technology (KB1000 series, Kahne Ltd., New Zealand), which is designed to measure rumen pH (acidosis, feeding behaviour, heat stress), rumen temperature (acidosis, heat stress, disease, estrous, mastitis, calving, drinking behaviour, stress, animal health and welfare) and rumen pressure (motility, acidosis, bloat).

Scientists choose their own sampling frequency to suit the application and their objectives and install their own identity (ID) prior to oral insertion into dairy and beef animals. Boluses assist scientists and researchers by providing a continuous flow of *in vivo* measurements from unrestrained cattle living under realistic commercial conditions.

Application of the sensors is also possible in metabolism studies where animals can be located close to the receiver. The bolus weighs approximately 65-75 g and Kahne recommends that the bolus is used in non-fistulated animals >300 kg. The bolus can be set to measure every 10 to 59 sec or 1 to 255 min, giving for researchers the flexibility to choose the appropriate interval for the investigation. Logging ability is good (Fig. 1).

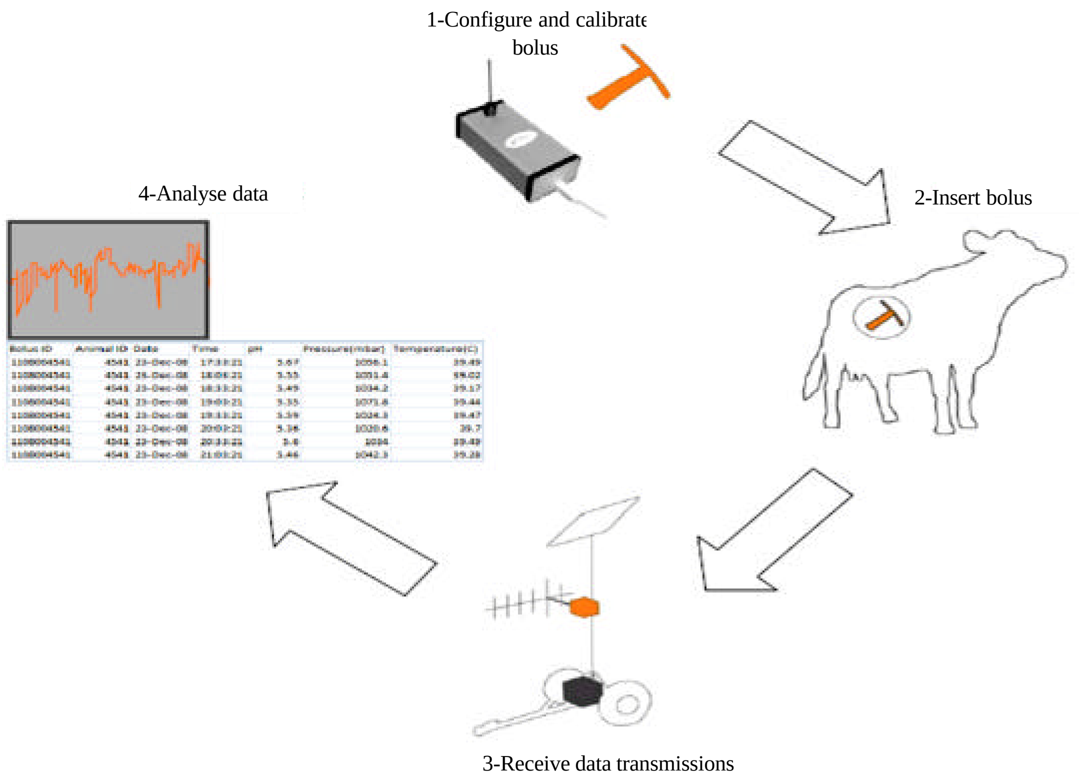

Fig. 1: Data collection using rumen boluses

Wireless rumen sensors can be used to determine changes in rumen conditions in cafeteria feeding systems. Rumen pH, pressure, temperature and feeding behavior can vary according to feed choice (Boga *et al.*, 2008). Some problems prevailing in studies such as *in vitro* gas production technique and *in situ* nylon bag technique (Kilic and Saricicek, 2004, 2006), where rumen cannulated animals need to be used, could be overcome by the use of wireless rumen sensors and the interpretation of results would be more reliable.

Placement of boluses in the rumen: In experimental period, boluses must be left in the rumen. Boluses must be repeatedly cleaned and recalibrated before each sampling period. The boluses, which come enclosed inside winged capsules to prevent loss from the rumen and can be easily inserted into the rumen through the esophagus. The boluses are easily inserted into the ventral sac of the rumen via the fistula by attaching it to a 35-40 cm long nylon thread to recover the boluses later. Initially, animals are left in a large pen area to assess the range of transmission. However, the signal is not captured when the antenna is more than 4 m away from the animal. Therefore, signaling must be controlled.

Placement of boluses in ruminally cannulated cattle or sheep is fairly easy such that the lid of canula is opened and the sensor is inserted into the rumen. It should be checked for 20 min whether is working properly (Kaur *et al.*, 2010; Wang *et al.*, 2006). Rumen boluses, which are to be used in sheep and cattle, should be in different sizes. However, it is reported that boluses suitable for cattle can also used in sheep. Trimming of the edges on top of the cattle boluses is recommended.

The use of rumen boluses for cattle was approved by Animal Ethics Committee. Their use like other studies with cannulated animals (nylon bag technique and *in vitro* gas production technique etc.) does not contradict with the ethical rules. However, some researches believe that wide use of rumen sensors in dairy cattle is not ethical (Bouma and Hilverda, 2005). It is thought that many meat processors in some countries (Australia) will not take cattle with rumen boluses (Gaughan, 2010). However, wireless rumen sensors have been approved by animal ethics committee although the number of scientific studies is limited.

Animal health: Technology is being developed to continuously monitor intraruminal parameters such as temperature and pH (Penner *et al.*, 2006). Additional technology will be required to analyze the large number of data sets collected by wireless sensor systems and subsequently determine important relationships (if any) among the response variables. Several important factors such as average ruminal pH, the pattern of ruminal pH over time, duration of suboptimal ruminal pH and the variation in the pattern of ruminal pH can be processed by artificial intelligence or other advanced computational programs to evaluate the significance of ruminal acidosis in cattle performance as well as in defining the relations between intake and acidosis (Nagaraja and Titgemeyer, 2007).

Determination of ruminal pH, temperature and pressure in animals can be crucial to suppress the occurrence of health problems such as subacute rumen acidosis and bloat. Owen *et al.* (1998) reported that rumen acidosis is a serious problem in dairy and feed-lot sectors, resulting in animal deaths, morbidity and diminished productivity.

Ruminal acidosis continues to be a common ruminal digestive disorder in beef cattle and can lead to marked reductions in cattle performance. The severity of acidosis generally depends on the amount, frequency and duration of grain feeding, varies from acute acidosis due to lactic acid accumulation, to subacute acidosis due to accumulation of organic acids in the rumen (Nagaraja and Titgemeyer, 2007).

The subacute rumen acidosis (SARA), which is assumed to be common in high yielding dairy cows, is attended by longer periods with rumen pH values < 5.5. Therefore, monitoring of rumen pH can be a possibility to recognize, quantify and subsequently control SARA (Zosel *et al.*, 2010).

Rumen wireless sensors can be used as a useful tool to develop feeding strategies through considering animal welfare. In this regard, the development of rumen sensors suitable for monitoring volatile fatty acids in the rumen will enable the researchers to find out the consequences of feedstuffs fed to ruminants. Through this approach, formulation of suitable rations or feeding programmes will be possible and be crucial for protecting health of animals in the future.

Rumen pressure: Rumen motility can be assessed by measuring changes in rumen pressure (Van-Soest, 1994). Thus rumen pressure can be used to determine bloat in ruminants. There is not a lot of rumen pressure data for cattle. Therefore, the boluses would be a very useful tool for assessing the relationship between rumen pressures on bloat in cattle (Gaughan, 2010). There were differences in the rumen pressure between the two steers (Fig. 2).

Rumen temperature: Al-Zahal *et al.* (2008) reported that the relationship between rumen temperature and rumen pH may be an indicator in the diagnosis of SARA. Rumen temperatures for two steers with bolus inserted into the rumen are shown in Fig. 3 and 4. The significant drop

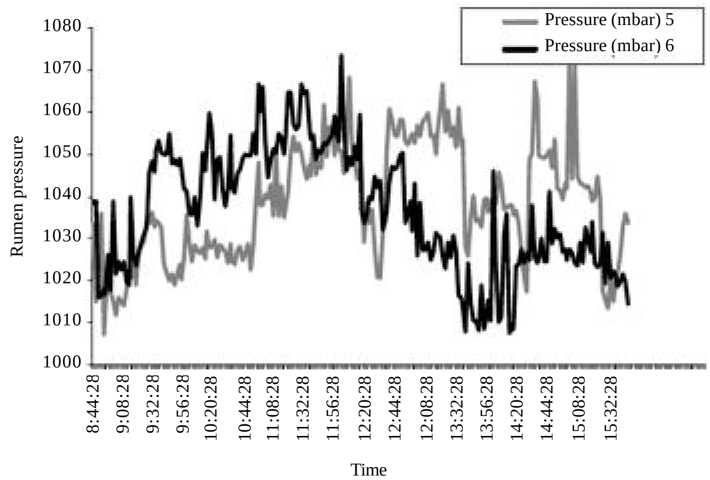

Fig. 2: Rumen pressure from two steers (Gaughan, 2010)

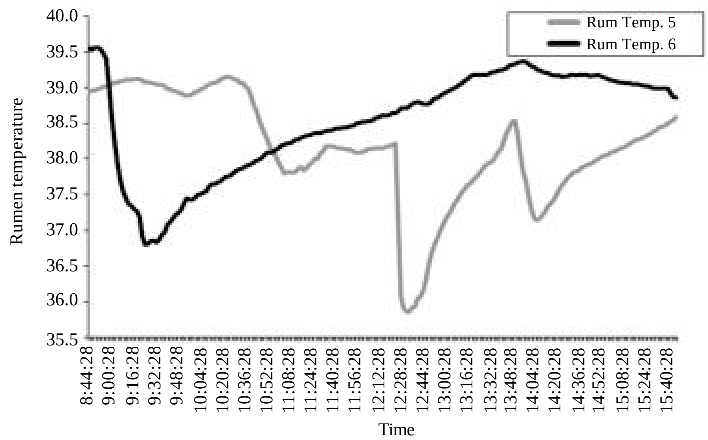

Fig. 3: Rumen temperature (Gaughan, 2010)

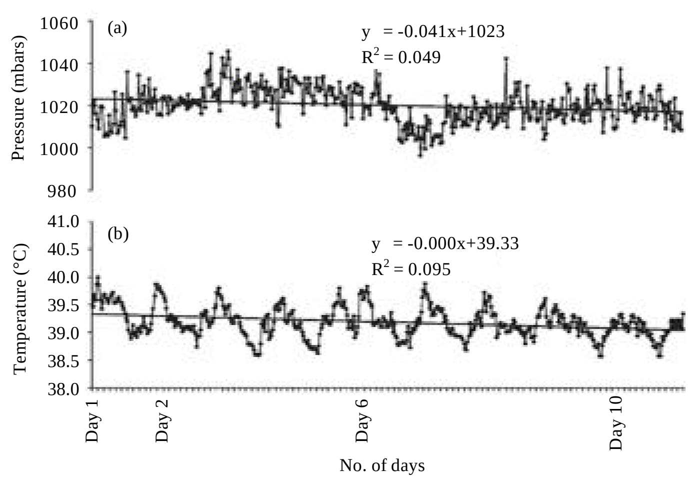

Fig. 4: Rumen temperature and pressure by a rumen bolus during a 10 day period (Kaur *et al*., 2010)

in the rumen temperature recorded by bolus 6 was due to the steer drinking a large amount of water at approximately 09:00 h when it was returned to its pen. The steer was not observed to drink again. The first reduction in rumen temperature of steer 5 corresponded to water intake and the second two corresponded to feed intake (Gaughan, 2010). The collection of data by boluses would probably enable to develop nutritional strategies, which would favor optimum rumen conditions.

Rumen pH: Monitoring ruminal fluid pH is a reliable method to determine acute acidosis or SARA (Penner *et al*., 2006). For research monitoring of rumen pH, a permanent device in the rumen is required to continuously monitor rumen pH remotely without interfering with the normal behavior of the animal (Kaur *et al*., 2010). Continuous acquisition of ruminal pH data has the capacity to facilitate understanding of the interactions between diet fermentability, intake and ruminal pH. The boluses have telemetry capabilities and a potential transmitting life of up to 5 years (Goopy and Woodgate, 2009).

The comparisons were made using steers that had been fed either a grain based diet, a hay based diet or a hay/grain diet (Table 1). The pH values can be shown in Fig. 5-7. The drop in rumen pH for steer 5 at points A and B in Fig. 5 correlates with the reduction in rumen temperature (Fig. 3).

Dado and Allen (1993), Penner *et al*. (2006, 2009), Goopy and Woodgate (2009) and Gaughan (2010) reported that the pH readings of the wireles rumen boluses were highly correlated (respectively, R^2 =0.87, 0.85, 0.89, 0.96 and 0.95) with a calibrated laboratory pH probe. The bolus probe pH values generally closely reflected those obtained using the conventional pH meter. However, there were some unexplained anomalies between the devices, which warrant further investigation before the boluses are used as standalone devices (Goopy and Woodgate, 2009). On the contrary (Fig. 7), in other studies resulted in a minor level of agreement between the two methods (Kaur *et al*., 2010). Zosel *et al*. (2010) reported that temporal changes of pH value and temperature can promote differences between the pH value of samples taken sporadically from the rumen and the values provided by the online probe. Penner *et al*. (2009) suggesting that the boluses can be used to measure ruminal pH in noncannulated small ruminants In conclusion, these rumen boluses need further advancement to be potentially used for continuous rumen pH measurements for research purposes.

Gaughan (2010) reported that the bolus mainly resides in the mat of the rumen (dorsal sac area). However, the boluses were located in the rumen reticulum on removal. Similar findings were reported by Mottram *et al*. (2008), who suggested that the location may give a slightly different pH to other areas within the rumen. Therefore, the location of boluses in the rumen should be taken into account in the interpretention of pH values obtained from the rumen.

Table 1: Spot measures of pH from the pH probe and boluses for steers feed grain, hay or hay/grain mix

Feed	pH probe	Bolus 5	Feed	pH probe	Bolus 6
Grain	5.58	5.55	Hay	7.09	7.11
Grain	5.47	5.48	Hay	7.31	7.28
Hay/Grain	6.19	6.22	Hay	7.27	7.28
Hay	7.23	7.19	Hay/grain	6.81	6.85
Hay	7.16	7.18	Grain	5.73	5.77

Gaughan (2010)

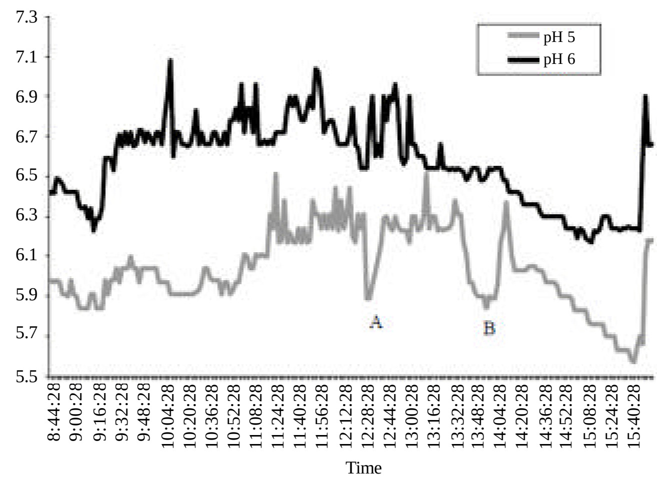

Fig. 5: Rumen pH of two steers fed a hay/grain diet (Gaughan, 2010)

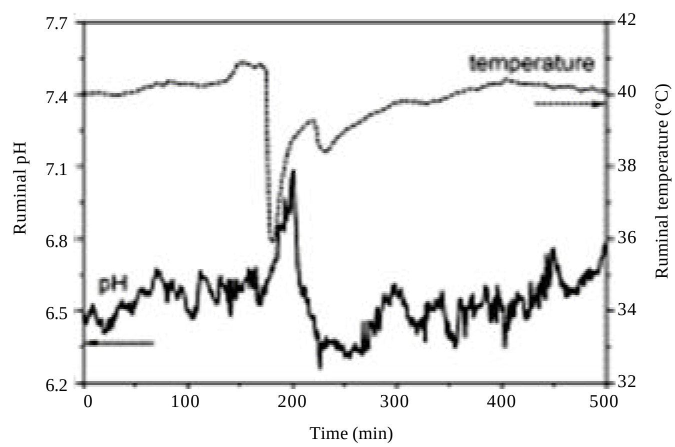

Fig. 6: pH value and temperature during long-term measurement in the rumen (Zosel *et al*., 2010)

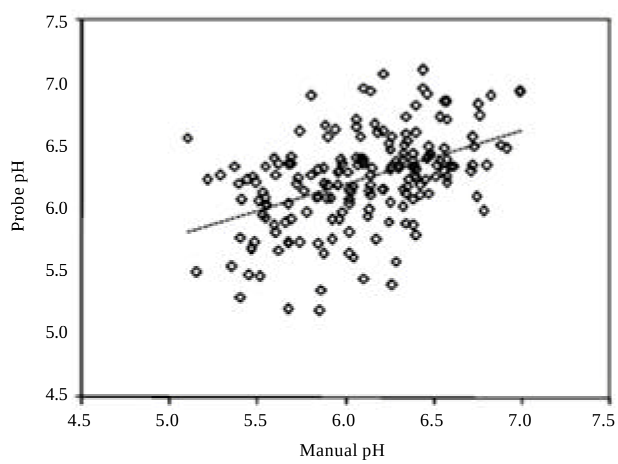

Fig. 7: Relationship between manual and probe method of determining rumen pH (Kaur *et al*., 2010)

Table 2: Received data from the boluses

Bolus ID	Date	Time	pH	Pressure (m bar)	Temperature (°C)
158	5/01/2010	12:20:00	6.54	985.1	39.65
158	5/01/2010	12:50:00	6.72	985.1	39.60
158	5/01/2010	13:20:00	6.60	980.2	39.65
158	5/01/2010	13:50:00	6.65	985.0	39.70
158	5/01/2010	14:20:00	6.65	985.1	39.70
158	5/01/2010	14:50:00	6.94	986.2	39.50

Data collection: There are some problems with the transmission of data from rumen wireless sensors via the receiver. At various times there appeared to be some sort of interference with the transmission of data, resulting in periods where no data was collected, but researchers were never able to determine the exact cause of the problem and after the initial run it never occurred again (Gaughan, 2010).

New developments enable you to obtain complete, comprehensive and accurate data sets from the rumen of animals at anytime, whether they are in free stalls, open paddocks or out on the range. Data is received and interpreted by the proprietary software via cable connection, wireless connection or manual download from memory card. The data can be viewed in Table 2 and/or graphical format either in a software or simply exported to Excel for analysis (Table 2).

CONCLUSIONS

Main obstacles of wireless sensor technology may include: standardization is not yet completed and the reliability of wireless system remains unproven and it is considered too risky for process control (Wang *et al*., 2006). An obvious advantage of wireless transmission is a significant reduction and simplification in wiring and harness (Sensors Magazine, 2004). The boluses were able to accurately record rumen temperature, pH and pressure. However, there is not a lot of data for rumen pressure. The bolus has the potential to increase our understanding of rumen dynamics.

In conclusion, these rumen boluses need further advancement to be potentially used for continuous rumen pH measurements for ruminant nutrition research purposed by Kaur *et al.* (2010). The development of sensors and computer systems goes very fast, things that now seem to be impossible, are maybe reality over twenty years. In the future, there is a need of wireless sensors which can measure greenhouse gases such as methane, carbon dioxide, ammonia and volatile fatty acids (acetic acid, butyric acid, propionic acid and lactic acid) in the rumen for ruminant nutrition researches. Therefore, animal nutrition studies can be commented more easily and also the most suitable feeding programme can be practiced (Kilic, 2005; Kilic and Garipoglu, 2009). However, it is essential to test the reliability of the data by preliminary studies and most reliable sensors should be used in animal nutrition studies. Wireless sensors and sensor networks have just entered at animal nutrition researches and they will have a bright future.

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