ABSTRACT

Objective: The objective of this study was to analyse data obtained with a telemetric pH- and temperature-measuring reticuloruminal bolus under field conditions.

Method: Before the expected calving date, the bolus was introduced into the reticulum of 8 cows. The bolus transmitted pH and temperature records to the internet at 10-minute intervals; the measured data were followed up until day 90 of lactation.

Results: The characteristic feed-intake-related diurnal changes in the pH value of the reticulum are illustrated in Figs 1 and 2. Immediately after calving, the average pH decreased for several days and the shape of the diurnal pH curve also changed. In the presence of metabolic disturbances such as ketosis and milk fever or organic diseases like puerperal metritis the average pH value and fluctuations characteristic of the individual cow tended to take more time to develop (Fig. 3c). The pH changes caused by certain feeding-related management defects (delayed feed distribution, TMR of variable quality) are illustrated by examples (Figs 5c and 6b).

Discussion: The possibilities of using this system under field conditions and in feeding trials based on sound scientific foundations are outlined in this paper.

Key words: Cattle, transition period, telemetric reticuloruminal pH bolus, peripartal diseases, acidosis index, SARA
The energy supply of ruminants, unlike that of monogastric animals, is provided by volatile fatty acids rather than glucose. Apart from a small proportion of dietary starch, the ingested carbohydrates (starch, sugar, pectin, cellulose, hemicellulose, etc.) are converted into a form utilizable by ruminants, i.e. volatile fatty acids (acetic acid, propionic acid and butyric acid), during digestion in the rumen. Volatile fatty acids serve as the main energy source also for the microorganisms (bacteria and yeasts) living in the rumen, supporting their propagation. If the production of volatile fatty acids is disturbed, this will adversely impact bacterial protein synthesis and, thus, indirectly impair the protein supply status of the body.

High milk production requires the production and absorption of large amounts of volatile fatty acids in a manner which is relatively well-balanced over time. A transient or lasting overproduction of volatile fatty acids may cause different digestive and metabolic disturbances of varying severity and, as an indirect effect of the former, may also lead to hormonal imbalances. The intensity of ruminal fermentation depends on the status and, what is inseparably from the former, the nutrient supply of the ruminal microflora; however, the actual feed intake is influenced by the current pH value of the rumen flora through a feedback mechanism.

If the pH of the rumen fluid often, typically recurrently over a period of several days, falls below a critical lower threshold (pH 5.8), subacute ruminal acidosis (a condition often referred to as SARA using the English acronym) may develop. This form of ruminal acidosis markedly reduces the digestibility of crude fibre and impairs the propagation of rumen bacteria, resulting in a consequent decrease in ruminal volatile fatty acid concentration and bacterial protein synthesis. The quantity and proportion of easily fermentable carbohydrate and fibre in the diet have a decisive role in the development of SARA. Lower milk fat content and, in some cases, reduced milk yield are economically important consequences of SARA; in addition, impaired immune responsiveness indicated by elevated milk somatic cell count develops and the prevalence of reproductive disturbances (Mátis et al., 2016), abomasal displacement and foot problems increases.

Short-term, diurnal changes in ruminal (ruminoreticular) pH are influenced by numerous nutritional and management factors, and the change of ruminal pH as a key parameter has impacts, even if only indirectly, numerous metabolic and digestive-physiological processes. Strictly speaking, the extreme values of ruminal pH, the rate of its change and the length of the period during which the pH fails to reach a certain lower threshold value (pH 5.8) indicate only that ruminal digestion is pathological or suboptimal, and do not give clues as to what the possible causes may be. However, the knowledge of these data may facilitate the exclusion or confirmation of practical hypotheses developed based on the local conditions of dairy farms, and can also be helpful in making assumptions on possible causes of this phenomenon.

No other directly nutrition-related clinical/clinicochemical or pathophysiological parameters are known which would respond to changes of the digestive processes so quickly as does the pH of the rumen content.

Like other clinicochemical parameters, the pH value of the rumen content primarily characterises the digestive-physiological status of the entire herd/production group rather than
of the individual animal, provided that a sufficient number of adequately representative samples are used for its determination. Although this approach is not always successful, partially because of individual variability, it is useful to analyse the pH and temperature data of the rumen content of ‘indicator’ animals and their difference from those recorded in the majority of animals in the herd, with the objective to explore the causes of increased susceptibility to SARA. It is of fundamental importance to keep the factors influencing the pH of the rumen fluid and the pathophysiological/metabolic consequences of these changes within limits that correspond to the intensity of feeding and the stage of lactation. Changes (typically a decrease) of the pH over a short or a longer period of time is of decisive importance as they precede and predict the potential risk of development of metabolic disturbances and feed conversion problems, thus providing a possibility to take corrective measures.

The majority of systems operating on a similar principle and supplied by different manufacturers measures also the temperature in addition to the pH. When using a sufficiently high number of measurements, a statistically significant negative correlation can be demonstrated between the two parameters, and this correlation is expressed if the pH decrease is rapid (Sato, 2016), this has moderate importance from the herd-diagnostic point of view to the current status of our knowledge.

It is an apt remark that ‘the change of rumen content pH is the mirror image of feeding’; however, we have to learn how to interpret these data.

The use of data obtained with telemetric measuring devices under field conditions and in applied science has produced wide-ranging results. For almost a decade, reports have been published on measurement-technical trials (Philips et al., 2010; Sato and others 2012) and then nutritional experiments (Gasteiner et al., 2014; Steinwidder et al., 2015) conducted with telemetric pH boluses, and data are already available also on their wide use in the field; however, so far only few technical papers have been written on the subject, especially on its latter aspect. The objective of this paper is to provide some data in order to gain a better understanding of the subject.

Experiences gained and observations made during the practical use of the VetAsyst reticuloruminal pH- and temperature-measuring bolus

The VetAsyst reticuloruminal bolus developed by Moonsyst Co. Ltd., located in the rumen or, because of the anatomic conditions, actually staying permanently rather in the reticulum, measures the pH and temperature of the reticulorumen at 10-minute intervals. The measured data are automatically transmitted via a wireless technology from the receiver installed in the barn to the internet and then to the user. Further information on the system is available on the website www.moonsyst.com.

By testing the system, we wished to determine how the data obtained through its use could aid the identification of nutritional and management errors and their prevention.
A high number of excellent publications have dealt with pH changes of the rumen fluid and with the problem of ruminal acidosis (Kleen et al., 2003; Krause et al., 2006; Plaizier et al., 2009). After studying these papers, for trying out the VetAsyst measuring system in the field we selected the transition (peripartal) period, which is the most critical time with a view to the development of pathophysiological problems and metabolic disturbances (Kleen et al., 2003).

Using a bolus insertion device used for the delivery of medicine in the field, we inserted a pH bolus into the rumen of 8 multiparous dry cows 10 days before the expected calving date. The VetAsyst pH bolus was tested in a high-yielding (average lactation milk production: 10,000 litres) Holstein-Friesian dairy herd of 500 cow spaces, using loose housing system with deep litter technology; data recording was continued at least until day 90 of lactation. The main findings of the measurements can be summarized as follows:

The ‘close-up’ TMR was fed in the three weeks before calving (NE\textsubscript{L}: 6.02 MJ/kg dry matter; crude protein: 14.7%; NDF: 40.4%). The ‘fresh cow’ TMR was identical with the TMR fed to cows in lactation (peak lactation and medium-level production), its main contents were NE\textsubscript{L}: 6.75 MJ/kg dry matter, crude protein: 15.8%, NDF: 30.8%. The feed change was performed on the day of calving. The postpartum body condition loss of cows was no substantial: when judged on days 30 and 60 of lactation, the average change was –0.2 points of body condition score.

The observations made during the use of the bolus were partially compared with the clinical signs shown by the cows, especially if the loss of appetite was a typical feature. If daily and diurnal changes were found in the pH of the rumen content, we tried to correlate these with management and nutritional defects, drastic weather changes, etc., and with the severity thereof.

It can be considered a ‘subsequent’, empirical evaluation if in a cow the characteristic diurnal variation of rumen fluid pH is distorted, its lowest point(s) is (are) critically enhanced or the course of the ‘pH curve’ greatly differs from those of the herdmates. The possible causes of this are analysed, and the findings are illustrated and shown in some figures.

After its high peak at dawn, the pH value rapidly decreases after the morning feed distribution, increases in the afternoon hours but its afternoon peak is lower than that recorded at dawn, reaches the daily nadir after the evening feeding, then returns to the baseline value in the dawn hours (in cows fed three times per day, a less important third peak can also be observed between the two above-mentioned peaks). The system provides measurements at 10-minute intervals, and the minimal +/− shifts of these data lasting for a short time do not have any significance. Expressed in a very simplified way, the ‘typical’ and the ‘atypical’ curves depend on the production and absorption of volatile fatty acids and the duration and intensity of rumination (saliva production).
**Fig. 1a.** ‘Typical’ diurnal variation of rumen pH (cow no. 6565, 1 October 2016)

It can be observed that the curve is markedly ‘**distorted**’ immediately after calving for a short time, in most cases for a few days, and then about two months later such distortions become more and more frequent, and the second daily peak becomes less expressed or is entirely absent.

**Fig. 1b.** Averaged diurnal variations of the pH of rumen content of the 8 cows used in the study (in a period of 30 days, in November)
Fig. 2. Diurnal pH changes typical of the protracted form of ruminal acidosis

This distortion is caused by the gradual decrease in the absorptive capacity of the ruminal epithelium and/or the insufficient duration and intensity of rumination in relation to the steadily increasing feed intake and the consequent volatile fatty acid production.

Changes in the pH of the rumen content in the peripartal period

After calving the appetite increases rapidly, and as long as the rumen microflora and the volatile fatty acid absorption capacity and surface of the ruminal epithelium do not become adapted, the decrease in the intensity of rumination and saliva production causes a moderate ruminal acidosis lasting for 3–6 days in some of the cows (Fig. 3a) (Arnaud, 2013). Subsequently the pH of the rumen content gradually returns to normal and its diurnal change becomes cyclical, as we could find in four of the cows having a reticuloruminal bolus. It occurs with a frequency varying by herd (in our case it was observed in four cows) that in the immediate postpartum period inflammatory diseases (metritis or mastitis), metabolic disturbances (e.g. ketosis or milk fever) or feeding mistakes increase both the severity and the duration of pH decrease and the degree and severity of ruminal acidosis (Figs 3/b and 3/c). Although feeding during the dry period is known to have a major effect on the development of postpartum ruminal acidosis, under the conditions of this study (because of the low number of animals and the identical feeding) this factor could not be investigated.

The risk of development of SARA must be reckoned with, although with a lower probability, even in herds with adequate farm management practices and also at a later stage of lactation.

Some authors consider pH 5.5 or 5.6, measured in rumen fluid samples taken by rumenocentesis or with a pH electrode in situ in the rumen, as the threshold value for establishing the diagnosis of SARA (Kleen et al., 2003). However, in the case of continuous pH measurement with the bolus in the reticulum, where the alkalizing effect of the continuously produced saliva is more pronounced, pH 5.8 should be regarded as the threshold value, and this value is used for calculating the ‘acidosis index’.
The following figures demonstrate the consequences of effects predisposing to a substantial drop in rumen pH or a typical SARA.

Fig. 3a. Changes in the pH of the rumen content after calving – transient, moderate acidosis (cow of ear-tag no. 6350)

A similar phenomenon has been observed also by other authors (Sato et al., 2012)

However, it could be observed in several cows that pronounced metabolic and organic disorders developed in association with a sudden change to a high-energy ration at the time of calving (Fig. 3b). (Feeding during the dry period and changes in the body condition score were not documented sufficiently).
Fig. 3b. Postpartum acidosis and ketosis are a consequence of a lasting decrease in rumen pH, expressed also in the ‘acidosis index’ (cow of ear-tag no. 6613)

The severe consequence of ketosis, diagnosed one week after the calving of cow of ear-tag no. 6613, is well indicated by the so-called acidosis index (acidosis index: the length of time within one day, expressed in minutes, during which the pH of the rumen content does not reach 5.8). It is very likely that in this case the reduced energy intake/utilization typical of SARA predisposed the cow to ketosis, and this latter, in turn, predisposed to the development of acute (puerperal) metritis. Incipient normalization of rumen fluid pH was very likely delayed by metritis, partially due to the reduced feed intake.

The following incidental finding was completely unrelated to the original objective of gaining experience with the use of the bolus; however, it is very interesting and edifying from a veterinary point of view:

Fig. 3c. Shortly after stillbirth severe ruminal acidosis developed, then as a result of the combined effect of subsequently recognised ketosis (BHB: 1.7 mmol/l) and acute metritis accompanied by fever and treated multiple times resulted in such a drastic decrease in the pH of the rumen content which was compatible with the diagnosis of protracted ruminal acidosis of a severity typical of the acute form (cow of ear-tag no. 6864). The severity of metritis is also supported by the fact that later on the cow became unfit for breeding due to chronic perimetritis accompanied by uterine adhesions.
Analysis of the later stages of lactation

It is known that there may be major differences between cows in the average pH value of the rumen content as well as in predisposition to acidosis (Humer et al., 2015; Dochme et al., 2008); a good example of this is cow of ear-tag no. 6532 (Figs 5a–d).

Fig. 5a. Changes in the pH of the rumen content of cow of ear-tag no. 6532 before calving and in the first 50 days after calving

Certain typical stages of the two-month test period should be looked at more closely. The given case is slightly similar to the imaginary ‘veterinarian’s horse’ on which all existing diseases can be demonstrated to the students. By analysing the continuous change of the rumen content pH of this cow, we can show the three predisposing factors and the typical manifestation of SARA in a closer view.

Fig. 5b. Changes in the pH of the rumen fluid of cow of ear-tag no. 6532 in the first five days after calving (calving date: 25 September)
At the time of calving, the changeover from pregnancy to lactation involves substantial hormonal and metabolic alterations (the so-called homeorhetic regulation), one of the consequences of which is the abrupt increase of appetite at the time of calving, followed by a decrease of feed intake in the subsequent few days. In this case the decrease or absence of chewing and rumination is accompanied by reduced saliva production; saliva is known to play a major role in the neutralization of the volatile fatty acids produced. The degree of postpartum acidosis is determined by the nutrient (energy) content of the pre- and postpartum ration, the gradualness of feed change, the composition of the rumen microflora, and the body condition of the cow. Fig. 5c illustrates a postpartum acidosis of higher than average severity and longer than average duration.

**Fig. 5c.** The decreased feed intake due to the defect of the feed carriage (on 4 October) resulted in an increase of ruminal pH on the same day and a strong decrease thereof (ruminal acidosis) subsequently, after excessive feed intake (cow of ear-tag no. 6532).
Fig. 5d. Transient acidosis due to the above-mentioned caused shown in Fig. 5c, or rather the substantial drop of the pH value – could be observed in all 8 cows (the pH values are averaged and the acidosis indices are added up). In other cases, however, the pH-altering consequences of effects disturbing the feed intake (e.g. group blood sampling) were observed in some of the cows only.

Fig. 5e. The effect of feed change and of feeding maize silage from freshly opened new depot but in the same quantity (22 October) on changes of rumen pH in cow of ear-tag no. 6532. This effect was less pronounced or absent in the other cows.

From the analysis of rumen fluid pH values of this cow, it can be concluded that ruminal acidosis caused by a decrease in feed intake, rumination and salivation, combined with milk fever non-responsive to therapy at the start of lactation, may have caused so severe damage to the ruminal epithelium that this cow became much more predisposed to subacute ruminal acidosis than her herdmates, for a long period of time. According to data of the literature (Dochme et al., 2008), even a single episode of severe acidosis can cause a lasting and severe impairment in the absorptive capacity of the rumen epithelium (by inducing hyperkeratosis) which may expressly predispose the cow to the recurrence of acidosis.
Such increased susceptibility could be observed e.g. following the defect of the feed distribution carriage on 4 October or after the feeding of new maize silage from a freshly opened silo. This silage was not yet stabilized adequately from the microbiological point of view and had high lactic acid content. In agreement with the opinion of other authors (Kleen, 2017), the irregular daily pH curves and the extreme pH values found after a feed change are strongly suggestive of an unstable rumen microflora.

**Other observations**

![Graph showing pH values over time]

*Fig. 6.* When analysing the results of a trial of similar design, conducted in another dairy farm with the pH bolus, we noticed that the occurrence of the pH decrease (expressed as acidosis index in the figure) at regular intervals coincided with the weekends. As a possible cause, it was suggested that at the weekends a different personnel was responsible for distributing the TMR. After adjustment of the technology this ‘phenomenon’ disappeared (the figure shows the summed acidosis index values of 8 cows).

**Discussion**

The results of our study conducted with the VetAsyst system confirmed the well-known fact that an abrupt change from TMR fed during the close-up period to lactation TMR may result in pronounced ruminal acidosis. Although the postpartum reduction of rumen pH is a general feature, every possibility should be utilized to decrease its extent (including the correct nutrition of dry cows that ensures a controlled energy intake and the gradual increase of energy intake after calving).

The indirect, delayed effect of ruminal acidosis occurring in the immediate postpartum period with a severity varying by individual (manifesting itself e.g. in the development of reproductive disturbances) is important primarily on herd level. Because of the low number of
animals used, in the present study it was not possible to perform a statistical evaluation of this effect. In addition to the experience presented above, in agreement with other authors we find it favourable if cows being at the same stage of lactation have a similar diurnal rhythm of rumen pH change and a moderate variation in the diurnal extreme values; however, it is even more important that the daily rumen content pH rhythm of an individual cow should remain similar over a long period of time. This latter may be indicative of the observance of technological discipline (homogeneity of the TMR, strict compliance with the feed distribution and milking times, etc.) (Mottram et al., 2014).

Farm management and its control may be supported by the analysis of cases where data obtained with the pH bolus demonstrate that management errors such as technical defects of the feed distribution carriage, delay in milking time, changes of the feed formula, grouping and other factors can cause major changes in the pH of rumen content, together with all the unfavourable consequences it may involve. To put it another way, analysis of the data obtained by the VetAsyst system may aid the self-control of farm management. When supported by adequate data, it can provide a feedback as to composition and homogeneity changes of the TMR also under field conditions; however, the technical aid presented in this paper in itself cannot propose specific corrective actions.

The analysis of values obtained by the pH bolus can be greatly facilitated by the simultaneous use of other methods such as the recording of rumination/chewing intensity or the determination of specific clinicochemical parameters (non-esterified fatty acids, net acid-base excretion, etc.).

Apart from its cost implications, continuous measurement of rumen fluid pH and the use of this system pose another question to consider, i.e. whether the user’s primary objective is to identify and eliminate management and feeding mistakes or he wishes to apply the system for confirming the cause and controlling the solution of a specific well-demarcated problem. Such a professional challenge may be e.g. minimising the losses occurring during heat stress by relying on the diurnal changes of rumen pH. This, however, requires a sufficiently deep knowledge of ruminal digestion, ruminal acidosis and nutrition. Successful application requires adequate documentation of the observations and the circumstances and their changes, as well as the continuous monitoring and analysis of the measured data. The analysis of data may be facilitated by the graphical, mathematical and statistical methods that currently exist or are being developed by several researchers.

The above examples primarily show the rumen pH changes induced by disturbing factors (e.g. management errors, metabolic problems), which may be very useful, as these cannot be examined in other ways, or can be examined only with a large margin of error. A further objective is to gain further experience for the practice, with the help of the users, by analysing the instantaneous and long-term diurnal variations of rumen pH in order to facilitate the optimisation of nutrition by utilising the short response time.
Proactive, farm-level testing possibilities of applied research type

It is well known that decreasing the distance between the diurnal extreme values of rumen pH (and primarily elevating the lowest point of rumen pH) involves multiple advantages, among others the stabilisation of the rumen microflora, as a result of which the fermentation products formed in the rumen will not impose a pulse-like burden on the cow’s metabolism.

The use of 8–10 ‘indicator’ cows fitted up with a reticuloruminal bolus under large-scale conditions provides a good chance of successfully studying questions like the effect or lack of effect of substantial changes in the (physical) structure and nutrient content of the ration, in the particle size (grinding fineness) of concentrate ingredients, the effect of changing the time and frequency of feed distribution and feed ‘push-ups’, as well as of adding or omitting buffer substances. The already mentioned rapid ‘response time’ offers a great possibility for performing a so-called ‘self-controlled’ experiment and analysing its results. If the rumen pH value of the ‘indicator cows’ significantly changes as a result of the ‘experimental question’, then this can be interpreted also in relation to the production and reproductive results of the herdmates. When using the boluses like we did in this study, the examination of cows only at a specific stage of lactation (even in the transition period when the cows’ metabolism is the most labile) does not allow us to draw conclusions valid for a longer period of the lactation. To avoid this, there may be (is) a practice when a bolus is inserted into 4–5 prepartum cows (pregnant heifers; this may also have advantages) monthly, which allows us to continuously monitor the critical first half of lactation. In order to ensure the interpretability of the results (considering the small number of animals and the individual differences), compliance with the technological discipline and documentation of the influencing factors are especially important.

The observations presented in this paper and the conclusions drawn from them have demonstrated the practical usefulness of a system of this type, which facilitates the fine-tuning of farm management as well as of the feeding strategy and technology. It should be mentioned, however, that without an adequate knowledge of the physiological background it is not possible to analyse the data correctly and to draw sound conclusions from them.

Conclusions

The nutrient requirements of cattle, which depend on the production level and also on other factors, can be calculated by approximate accuracy, although the feed evaluation methods slightly vary by country. However, even if the values obtained by modern in vitro and in vivo parameters estimating the rate and speed of ruminal degradation are known, it is not always easy to predict the degree and rate of the ruminal degradation of carbohydrates, e.g. because of exogenous causes (such as management errors, weather factors). Knowledge of the continuous diurnal variations of rumen pH may help us identify feeding and management mistakes and prevent SARA. Using a telemetric reticuloruminal bolus under field conditions in a dairy farm, we monitored the changes occurring in the pH and temperature of the rumen content in the transition (peripartal) period. In this way we could demonstrate that a not sufficiently gradual feed change implemented in the peripartal period induces a ruminal
acidosis of individually variable severity and duration. In some cases, the mutual interaction of the decrease of rumen fluid pH with pronounced SARA and some other metabolic disturbances and organic diseases (milk fever, ketosis, puerperal metritis) could also be suspected. The experiences gained with this diagnostic tool are promising also with a view to analysing the results of feeding trials performed under field conditions (even in a self-controlled design) or the consequences of technological changes (e.g. the change of feeding time).

References


