Estimation Methodologies for Enteric Methane Emission in Ruminants

13

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Abstract

As enteric methane emissions from ruminants contribute to feed inefficiency and global warming, methodologies to measure the enteric methane from either the individual ruminant or the herd are needed. Therefore, methane emission estimations in ruminants may provide insight into potential methane mitigation strategies. Furthermore, the use of methane emission methodologies enables researchers to compare and contrast methane emissions from different diets, breeds, and geographical locations and to evaluate mitigation strategies. This chapter describes key methane estimation methodologies previously and currently used in research and highlights the advantages and disadvantages of each methodology. Key in vivo techniques include open- and closed-circuit respiration chambers, open-circuit hood systems, sulfur hexafluoride (SF_6) tracer, polythene tunnel system, methane/carbon dioxide ratio, GreenFeed, infrared (IR) thermography, laser methane detector, and the intraruminal gas measurement device. Furthermore, the in vitro gas technique (IVGT) estimates the methane emissions from different dairy rations. Theoretical methodologies include the rumen fermentation balance, COWPOLL ruminant digestion model, and the Cattle Enteric Fermentation Model (CEFM). Although there are several different types of methane estimation methodologies, the cost, species, accuracy of the technique, maintenance, and the environment of the ruminant are all contributing factors in choosing which technique to apply to a study.

Keywords

Enteric methane emissions • Estimation methodologies

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13.1 Introduction

Globally, enteric fermentation accounts for 28 % of the estimated anthropogenic methane emissions (EPA 2013). With an expanding global population and demand for beef and dairy products, methane emissions are projected to significantly increase by year 2020 (Global Methane Emissions and Mitigation Opportunities 2014). Because methane has a 12-year lifespan in the atmosphere, it is a short-term climate forcer. While methane is in the atmosphere shorter, and is produced in smaller quantities than carbon dioxide, it has a global warming potential (GWP) 25 times that of carbon dioxide, making it one of the most important greenhouse gases contributing to climate change (EPA 2010).

As a response to global and country-specific enteric methane emissions, scientists have come up with several methane mitigation strategies and methodologies for estimating enteric methane emissions from ruminants. Emphasis on the latter will be the focus of this chapter. If the overall goal is to mitigate methane, then it is important to understand how much methane ruminants are producing and how much is being abated on an individual and whole herd basis. This chapter will focus on a variety of popular methods for estimating individual animal enteric methane emissions. A description of the functionalities of each method and the advantages and disadvantages of each methodology will be presented.

13.2 Closed-Circuit Respiration Chamber

Turner and Thorton (1966) developed a closed-circuit respiration chamber in 1966 that was completely sealed and measured the change in air composition. The closed-circuit chamber has air conditioning, a cage to hold the animal, and feed and water bins. Gas analysis occurs as air is pumped continuously from the chamber through a sampling circuit that contains a dust trap, solenoid, and relief valves. An infrared analyzer is used to record methane and carbon dioxide concentrations. According to Turner and Thorton (1966), each run can range from 30 to 100 min and is dependent upon animal size and state. Wright et al. (2004) described placing sheep in closed-circuit chambers for 13.5 h for 5 consecutive days. The sheep on this study also received 30 min of acclimation. Because the system was closed, the chamber was raised or "opened" for approximately 12 min every 2–3 h to expel the carbon dioxide. When the chamber is lowered again, the system is then considered "closed."

Cost is the biggest disadvantage to this methane emission estimation methodology. Because carbon dioxide can build up in the closed system, an operator needs to be present to open the system, making it more difficult to measure total exchange over a long period of time (Turner and Thorton 1966; Wright et al. 2004). By opening up the system, Turner and Thorton (1966) noted that it could become more difficult to keep ambient air in. Although the closed-circuit system has several disadvantages, it still is highly precise in comparison to other techniques. If researchers prefer to use an open-circuit respiration chamber, then the closed-circuit respiration chamber can be easily converted into one.

13.3 Open-Circuit Whole Animal Respiration Chambers

The use of whole animal open-circuit respiration chambers has been the gold standard method to estimate individual methane emissions of small and large ruminants. In fact, the validity of other methodologies presented in this chapter is determined by comparing results to data collected with the use of whole animal respiration chambers (Johnson et al. 1994; Chagunda et al. 2009; Montanholi et al. 2008).

With the open-circuit indirect calorimeter, a known flow of air is circulated around the animal's head, nose, and mouth, and expired air is collected (McClean and Tobin 1987). Methane emissions can be determined by measuring the total airflow through the system and calculating differences between inhaled and expired air (Johnson and Johnson 1995). Both carbon dioxide

and methane are determined with an infrared analyzer, while oxygen concentrations are determined by a paramagnetic analyzer (Miller and Koes 1988). The chamber is completely sealed and has a negative pressure created by outside air to ensure that all potential leaks that could affect methane emissions go inward. The chamber temperature is maintained by circulating air going through the evaporator assembly (Miller and Koes 1988). Before going through the infrared and paramagnetic analyzers, all moisture from the air samples is removed by a desiccant.

Although the design of respiration chambers varies by experiment and facility, all chambers typically have similar components. The respiration chamber contains a cage to house an individual animal (e.g., cattle or sheep). Within the cage, waterers, feeders, fecal and urine collectors, air conditioning, and dehumidifiers are all necessary for animal comfort (Chagunda et al. 2009). Before starting an experiment, the animal must be acclimated to the chamber. Typically, the animal gets acclimated to the chamber for 4–6 h, multiple times. Once the animal becomes acclimated to the chamber, then gas measurements can be calculated.

Johnson and Johnson (1995) noted that respiration chambers can measure both enteric and hindgut methane emissions in an individual, giving a more accurate estimate of the total methane produced by the animal. The biggest disadvantages to using a respiration chamber are the cost due to construction and maintenance and the lack of a comfortable, normal environment for the animal. The chambers attempt to create a comfortable environment, but changes in animal behavior could be an issue as ruminants like sheep and cattle are herd animals that like to socialize with other members of their herd. It is proposed that by creating an artificial environment, the animal's dry matter intake (DMI) will be altered. DMI is a key component that drives methane emissions (Ellis et al. 2007) and would decrease under these chamber conditions (Johnson and Johnson 1995). Therefore, it is believed that the use of an immobile respiration chamber cannot be applied to animals on pasture. Although cost is the major drawback to using respiration chambers, this technique is still considered the gold standard for the most accurate estimates in comparison to the other techniques that will be discussed below.

13.4 Open-Circuit Ventilated Hood System

The ventilated hood systems use the same principles as the whole animal chambers to measure methane concentrations, but are less expensive and portable. Kelly et al. (1994) developed a mobile, open-circuit indirect calorimetry system that contains a hood system with an airtight headbox. The system uses two separate but linked sampling lines. The mainline involves the movement of gas across a ventilated hood worn around the animal's neck with subsequent measurements of airflow, absolute pressure, relative humidity, and temperature. The hood fits small ruminants and was originally made primarily of plywood (Kelly et al. 1994). The hoods have acrylic windows and a removable rear panel for feeding and watering that is sealed with butterfly clips and foam to prevent leakage. The front of the hood has an opening for the animal to put its head in. A nylon drape attached to the hood is secured around the animal's neck with an adjustable string.

Odongo et al. (2008) also used the same principles of the whole animal chamber along with the previous hood system to create an open-circuit ventilated hood system for estimating methane emitted from lactating Holstein dairy cattle under two diet treatments. Furthermore, Place et al. (2011) utilized basic dimensions and design from both Kelly et al. (1994) and Odongo et al. (2008) to construct a ventilated hood system that measures greenhouse gases and volatile organic compound emissions. Because the headboxes are made out of clear polycarbonate material, cattle can have a full range of vision while they are temporarily placed in the headboxes for sampling (Place et al. 2011). By having a full range of vision and movement, the animal can be more comfortable and less stressed.

The biggest advantage of using ventilated hood systems is that it is less expensive than a whole animal chamber. It also requires less space and is mounted on a cart with wheels so that it can be moved from one location to another. According to Place et al. (2011), the ventilated hood systems are more accurate than the SF_6 tracer technique that will be explained later in the chapter. The biggest critique of the technique is that the animal is restrained and therefore needs to adapt to the system.

13.5 Rumen Fermentation Balance

Using a series of assumptions about fermentation and volatile fatty acids (VFAs), Wolin (1960) came up with an equation, called the theoretical rumen fermentation balance for predicting methane and carbon dioxide in ruminants in correspondence to the molar distribution of VFAs in the rumen. The following assumptions were made: (1) there is no hydrogen associated with microbial cell synthesis; (2) the fermentation of noncarbohydrate substrates results in no VFAs; (3) the molar proportions of VFAs in a rumen fluid sample are 65 acetic acid: 20 propionic acid: 15 butyric acid, representing the proportions in which they are produced from substrates; and (4) all the carbohydrates are of the same empirical formula, $C_6H_{12}O_6$. The fermentation balance is evaluated with experimental data with product-substrate relationships to determine theoretical methane to carbon dioxide ratio. Furthermore, Ørskov et al. (1968) explored the VFAs, acetic, propionic, and butyric acids and stated that the fermentation balance suggests that there is a correlation between methane losses and acetic acid. For example, with an increase in acetic acid production, more hydrogen is available to reduce carbon dioxide to methane. In contrast, propionic acid has an inverse effect, while butyric acid has an intermediate effect on methane.

Since this technique uses equations to indirectly estimate methane emissions, it has received several criticisms. The technique was established in 1960 when the other methodologies revealed in this chapter were not yet developed. Considering the age of the technique and the lack of other techniques during this time, the rumen fermentation balance was a start to establishing methods to estimating methane emissions.

13.6 In Vitro Gas Technique

The in vitro gas production technique (IVGPT) or in vitro gas test was originally used to predict the fermentation of ruminant feedstuffs. With methane's contribution to greenhouse gas emissions and methane's inability to be used as an energy substrate, the IVGPT has been applied to examine methane production from different feed ingredients predominantly seen in dairy rations (Lee et al. 2003). The overall goal of using this method would be to quantify the methane produced from the ration, compare rations from commercial farms, and to alter rations to be more feed efficient for the animal and contribute less methane into the environment.

Although there are several different methods and alterations to measuring gas production, the basic principles of all the techniques are the same: ferment feed with naturally occurring rumen microorganisms. A fresh rumen digesta sample is collected and filtered through cheesecloth to remove any large feed particles. To avoid a change in the microbial population, carbon dioxide is flushed into the containers holding the experimental samples. Over a series of time points, from 0 h up to 144 h, the feedstuff, buffer, mineral solution, and rumen fluid are incubated at 39 °C in a water bath (Lee et al. 2003; Storm et al. 2012; Getachew et al. 2005). The total amount of gas produced during the incubation is measured and analyzed to predict the amount of methane produced. Methane can be determined by injecting 100 ml of the gas from a glass syringe with an outlet containing a gastight septum into a gas chromatograph (GC) with a thermal conductivity detector (Getachew et al. 2005). Getachew et al. (2005) ran each incubation in duplicate, and gas samples were collected from each syringe at 6, 24, 48, and 72 h from the syringe septum. The amount of gas produced by

fermentation of the substrates in the feed can estimate digestibility and metabolizable energy. The IVGPT measures the fractional degradation ratio of feed matter disappearance per unit time and the amount of methane produced per gram dry matter (Storm et al. 2012).

Although the basis of the technique is consistent, there are some variations to the methods used to measure in vitro gas. Menke et al. (1979) described an IVGPT where gas produced from fermentation was used to estimate digestibility, but 0.2 g of air-dry material or feedstuff was added to a 150 ml glass syringe with a buffered medium and rumen fluid inoculum that was incubated at 39 °C in a water bath. The total gas production was measured by reading the position of a piston at different time intervals (Mauricio et al. 1999). In contrast to Menke et al.'s (1979) technique, Wilkins (1974) incubated the substrates and rumen fluid in a sealed serum flask with fermentation gases building up in the oxygen-free headspace of the flask. A technique employed by both Pell and Schofield (1993) and Tedeschi et al. (2008) uses an in vitro fermentation chamber where the substrates, buffer, and rumen fluid are within flasks that had pressure sensors attached. Other techniques include fully automated systems and the rumen simulation technique (RUSITEC) that uses rumen effluent from simulated rumen fermentation, but has lower microbial activity than natural rumen fluid (Storm et al. 2012).

Some advantages to using the IVGPT technique are that it is relatively inexpensive to other methane estimation techniques such as respiration chambers. Typically, the duration of these experiments is 1–4 weeks and can compare multiple feedstuffs from different commercial farms at a time. Aside from the initial collection of rumen fluid in vivo, the technique resides in the laboratory without the use of live animals, thereby decreasing the labor intensity of the procedure.

The biggest criticism of using the IVGPT is that it is a simulation of how the feedstuff is fermented in the rumen and not a technique that gives the individual animal's methane emission estimates and total digestibility in the whole animal (Storm et al. 2012). The gas release captured by this technique is related to degradation, but gives no information about the extent of degradation or the quantity of fermentation products (i.e., microbial proteins and volatile fatty acids) (Mauricio et al. 1999). This technique does not account for the long-term adaption of the rumen microorganisms to feedstuffs under a normal rumen environment. For example, bacteria are estimated to adapt to a change in feedstuff within 4 weeks, while methanogens adapt between 4 and 12 weeks (Williams et al. 2009). Although this technique has several flaws, it is a good basis for testing new feedstuffs and comparing rations that could potentially launch an in vivo experiment using live animals.

13.7 Sulfur Hexafluoride (SF_6) Tracer

The SF_6 tracer procedure designed by Johnson et al. (1994) estimates methane emission rates from cattle and sheep in their natural environments. SF_6 is used to simulate the methane emission rates from the mouth and nostrils, as the dilution rates are very similar to methane and are nontoxic to the animal. Before measuring the methane emissions in vivo, small permeation tubes containing liquid SF_6 are prepared in the laboratory. The tubes are placed in a 39 °C water bath and weighed until accurate loss rates are determined. Permeation rates of 500–1,000 ng of SF_6/min are suggested (Johnson et al. 1994).

Before the permeation tubes are inserted into the rumen, the animals go through an acclimation period that is dependent upon the individual animal being sampled, ranging from 1 day to a week. A balling gun inserts the permeation tube containing SF_6 into the rumen. Contrary to the Johnson et al.'s (1994) acclimation period and tube insertion procedure, Pinares-Patiño and Clark (2008) and Pinares-Patiño et al. (2008) used a 10-day acclimation period and used fistulated cattle so that a balling gun was unnecessary. Although acclimation periods and routes of permeation tube insertions vary by study, the action of the sulfur hexafluoride (SF_6) is the same. Once

in the rumen, the permeation tube will release SF_6 at a constant rate, and both SF_6 and methane concentrations can be measured at the mouth of the animal. Once SF_6 release rates and methane and SF_6 concentrations are measured, the following equation can be used to determine the methane emission rate (Sheppard et al. 1982):

$$Q_{methane} = Q_{SF_6} \times [CH_4] / [SF_6]$$

In their original article, a 1-L stainless steel collection vessel and a capillary tube extending from the collection canister were used above the animal's mouth and nostrils for sample collection (Johnson et al. 1994). There is a collar around the animal's neck for the canister to attach to a transfer line. Prior to sample collection, the canister is evacuated. To start sample collection, a valve on the collection vessel is opened as the evacuated canister is filled at a constant rate until it reaches 0.5 atmospheres (atm). Once this occurs, the canister valve is closed to stop sampling. The air that is collected in the canister passes through a sample loop with a flame ionization detector (FID) that is attached to a calibrated GC. Quantification of methane production is observed comparing the peak heights and retention times of the samples to a set of standards (Johnson and Johnson 1995).

Although the SF_6 tracer method enables researchers to estimate the methane emissions from ruminants in their natural settings, such as pasture and free stalls, there are several flaws displayed by this technique. Both McGinn et al. (2006) and Pinares-Patiño et al. (2008) noted that although the method does measure the methane eructated by the animal, it fails to measure the 5–10 % of the methane from the rectum (Johnson and Johnson 1995). Furthermore, in comparison to the chamber method, the SF_6 tracer technique both underestimates and overestimates methane emissions when compared to open-circuit indirect calorimetry techniques, making it a less accurate technique (Pinares-Patiño and Clark 2008; Pinares-Patiño et al. 2008; Grainger et al. 2007). Pinares-Patiño et al. (2008) also noted that there is an uncertainty about the permeation rate of the tubes associated with length of time between calibration and trial use. Some researchers argue that the SF_6 tracers generate inaccurate readings and are highly variable in data recorded from the same animal in consecutive days. This variability is from dust and water blocking the capillary tubing, from leaks in the polyvinyl chloride (PVC) yolks used around the animal's neck or from poor ventilation (Pinares-Patiño et al. 2008; Wright et al. 2013).

13.8 Polythene Tunnel Systems

A polythene tunnel system was designed to draw air through a large tunnel and measure methane concentrations in air entering and leaving the tunnel with gas chromatography. Lockyer and Champion (2001) used the polythene tunnel, previously explained by Lockyer and Jarvis (1995), to measure methane production in sheep in relation to changes in grazing behaviors. While measuring methane, video recordings of the animals' eating and ruminating behavior were observed.

The polythene tunnel consists of one large tunnel that is portable and can be placed out on pasture, unlike whole animal respiration chambers. The animals contained in the tunnel are still able to graze on pasture, while their methane emissions are measured. Within the large tunnel, variable speed coaxial fan and two smaller tunnels blow air into and out from the larger tunnel. An apparatus inside the tunnel measures and records the methane in air entering and leaving the tunnel while monitoring the airspeed, humidity, and temperature.

Some of the challenges of using the tunnel system are that different dietary treatments cannot be used as the animals in the tunnel are grazing on the pasture under the tunnel (Bhatta et al. 2007). It was observed by Lockyer and Champion (2001) that animals contained in the tunnel for 10 days had consistent methane emissions to other studies using the polythene tunnel, but had decreased methane emissions in comparison to studies with open-circuit indirect calorimetry.

13.9 Methane/Carbon Dioxide Ratio

With the use of carbon dioxide as an internal marker to estimate methane emissions, the methane/carbon dioxide ratio determines how efficient microbial fermentation is on feed and therefore uses feeds or cattle with the great energy conversion abilities and low methane emissions. From data collected from metabolizable energy (ME) intake or from heat-producing units (HPU), the total concentration of carbon dioxide can be estimated. The intake ME minus the weight gain or milk produced by the animal will yield the amount of carbon dioxide excreted. To determine the methane/carbon dioxide ratio, a portable device called a Gasmet (Gasmet Technologies, Oy, Helsinki, Finland) samples air in barns or around individual animals, while the amount of carbon from fat, carbohydrates, or proteins not metabolized to carbon dioxide can be estimated as methane emissions (Madsen et al. 2010). To calculate the amount of methane emitted, the same equation from the SF_6 tracer method is used with carbon dioxide replacing SF_6.

When cows eructate carbon dioxide and methane, the respective concentrations are 100 and 1,000 times higher than the concentrations found naturally in air (Storm et al. 2012). Therefore, Madsen et al. (2010) state that a low amount of an animal's breath needs to be sampled (i.e., 2–3 %). Another benefit of this methodology is that it is versatile. Since the device that measures the gases in the breath and air is portable, both individual and whole herds can have their methane emissions estimated in different environments. Although this method does not measure the methane emissions from the rectum, it still measures the majority of the methane emitted from the animal (Murray et al. 1976).

One of the challenges of this technique is that both CO_2 production and the animal's energy requirements are influenced by the same factors: size, production, and activity (Storm et al. 2012). In comparison to the respiration chamber technique, this method also has more variation between day-to-day measurements, leading to an increased standard error. To address this variation, larger sample numbers are required and are easier to obtain as this method is noninvasive and does not disturb the animal in an unfamiliar environment like the respiration chamber does.

13.10 GreenFeed

Another means of measuring methane emissions in cattle is the GreenFeed system, created by Zimmerman and C-Lock Incorporated (Zimmerman 1993). The system is versatile in that it can measure methane and carbon dioxide emissions from both dairy and beef cattle in different environments such as pasture, free stalls, and tie stalls. The GreenFeed system is a "turnkey-based system" with a "baiting station" that can quantitatively measure both methane and carbon dioxide.

GreenFeed works when an animal sticks its head into the instrument and receives a small amount of food as an award. To prevent any discrepancies in methane measurements due to a varying diet and frequency of animal visits to the instrument, the typical food reward (150–300 g) that the animal receives is allotted to 3–5 times per day and is similar to the ration that the animal consumes on a daily basis. Once the animal sticks its head into the instrument, a radio frequency identification (RFID) system identifies the animal. A fan draws air over the animal's nose, mouth, and head into an air-handling system where airflow rates, gas concentrations, and the volumetric flux (liters/minute) of gases emitted by the animal are calculated. Once the volumetric flux is calculated, the mass flux (grams/minute) can be calculated in conjunction with the ideal gas law ($PV = nRT$) where P is the pressure of the gas, V is the volume of the gas, n is the amount in moles of the gas, R is the ideal gas constant, and T is the absolute temperature. After an animal's emissions are measured, the information goes to the analyzing station, and the unit resets for the next animal to enter (Zimmerman 1993; Waghorn et al. 2013).

As of 2012, there have been 18 GreenFeed units installed in seven countries, and they have been tailored to the environment in which it is to be used. In the United States, a GreenFeed system at Washington State University (WSU) can still operate during a harsh winter and only requires a low amount of power (i.e., 50 watts). At Pennsylvania State University (USA), the unit moves on wheels, between cows housed in tie stalls. To get an estimate of the methane emitted from each cow in a tie-stall operation, the cow's methane is measured for 5–7 min, 5 times per day. Another one at Michigan State University (USA) is installed into a robotic milker at the Kellogg Biological Research Station.

There are several pros of using the GreenFeed unit versus other techniques. The unit itself is standardized and is low maintenance in that it takes 15 min per week to change out the air filters and calibrate the unit. Unlike respiration chambers or headboxes, the animals can be measured under grazing conditions. The unit also uses a low amount of energy and receives its power supply by the solar panel connected to it. However, it was noted that WSU had to use an AC adapter to help power the unit in the winter.

One of the biggest challenges with the GreenFeed method of measuring methane is that methane emissions are taken at all times of the day for each animal. For example, cow A could enter the unit and receive bait before a meal when methane emissions are typically low and cow B could tend to enter the unit after a meal when methane emissions are high (Montanholi et al. 2008). Multiple time points during the course of the day are supposed to make up for this potential disparity, but the animal's ability to enter the unit cannot be controlled. There is a potential that an animal will not have any interest in the unit or that a dominant animal may prevent a more submissive animal from entering.

Although, the unit measures the methane that exits the animal's mouth and nose, it does not get a complete estimate of methane emissions as it does not measure the 5–10 % of the methane that is emitted from the rear of the animal (Murray et al. 1976). The majority of the methane would be measured with this unit, but does not collect 100 % of the methane emitted from the animal as a closed respiration chamber does.

13.11 Infrared Thermography

It has been suggested that there is a correlation between decreased body surface temperatures and increased feed efficiency in cattle (Montanholi et al. 2006, 2007). The production of methane results in an estimated 2–12 % gross energy intake that makes the animal less feed efficient (Johnson and Johnson 1995). Knowing this information about feed efficiency and there being insufficient comparisons made between infrared (IR) thermography and actual methane and heat production, Montanholi et al. (2008) demonstrated that methane emissions from cattle could be estimated by comparing thermal images captured with an IR camera from the right and left flanks of dairy cattle to methane emissions measured by an open-circuit indirect calorimetry system.

The IR camera is portable and can be used without coming into contact with the animal. Before use, the camera is calibrated with the current room temperature and humidity. To get more accurate readings, it is suggested that the animal's body surfaces be free from excess debris and that measurements be taken with the animal out of direct sunlight (Poikalainen et al. 2012). When aiming the camera at a body surface of the animal, such as the left flank, the camera sits atop a tripod, 1.5 m away from the body surface, and an image is captured (Huntington et al. 2012). The camera converts the skin surface's emitted radiation from wavelengths to an electrical signal that is converted into a thermal image. It is suggested that thermal images be captured every 20 min for a total of 20 time points, indicating that it takes 6.5 h to generate data from one animal.

In the study by Montanholi et al. (2008), it was noted that there was only a 0.1 °C difference between the left and right flanks, and temperature fluctuations coincided with feeding. The temperature difference detected by the IR camera between the left and right flanks coincided with

the methane emission pattern that was observed from the animals in the open-circuit calorimeter. Furthermore, it was concluded that differences between the left and right flank temperatures are good indictors of methane estimates, but only at certain times of the day. The postprandial period, roughly 100 min after a meal, was advised to be the best time to assess the methane production via IR thermography and demonstrates fluctuations in rumen temperatures (Montanholi et al. 2008). Some advantages to using IR thermography are that the technique is fast, noninvasive, and less expensive in comparison to other methane estimation technologies and enables the animals to be in their normal environments (e.g., free stalls, pasture, or tie stalls). The IR camera also provides instant results that are stored in computer files so that the researchers can better manage the large amount of data they are collecting on farm.

Although there are several benefits to IR thermography, there are some issues and parameters that must be followed to get accurate results. As mentioned before, thermal images must be taken out of direct sunlight and out of the wind, as these factors can alter the body surface temperatures (Poikalainen et al. 2012). Because it takes 6.5 h to generate data from one animal, the technique can become time consuming and labor intensive with increased herd sizes. Another issue is that there needs to be a way to calibrate methane with temperature. This technology does not quantify the methane that is produced so there is a need to calibrate temperature with methane.

13.12 Laser Methane Detector

Originally, the laser methane detector (LMD) was created by the Tokyo Gas Co. for measuring methane emissions in sewage systems, mines, and demolition sites. However, it was recently suggested by Chagunda et al. (2009) that this device could be used on commercial farms to estimate methane emissions in individual cattle and sheep that could benefit greenhouse gas mitigation strategies and feed efficiency concerns. The LMD is a handheld device that uses infrared absorption spectroscopy and uses second harmonic detection of wavelength modulation spectroscopy to determine the methane concentration.

To use the handheld device, a semiconductor laser beam is directed at the preferred area of detection (i.e., the nostrils). The data that are obtained from each measurement are stored on a memory card that can then download readings onto a computer. Measurements are obtained via gas column density, and methane concentrations are given in part per million (ppm). Chagunda et al. (2009) used LMD to measure methane emitted by four sheep and two dairy cows that were housed for 8 h in an open-circuit respiration chamber. Every 30 min, samples were collected from each animal with methane measurements taken every 0.5 s within a 5-min window. While measuring each animal, researchers note the activity of the animal (e.g., ruminating, standing, eating, lying) along with the weather conditions (Chagunda et al. 2013). By noting these conditions, a correlation of methane and activity was made by Chagunda and Yan (2011), indicating that methane emissions in ppm increased directly after feeding.

The use of a LMD to detect methane is safe for the operator of the device to use because no animal contact is needed, and it is ideal for the animal, in that it is a noninvasive, stress-reducing technique that predicts methane emissions of individual animals in their natural environments. Because it is portable, methane emissions can be estimated in different production systems such as pasture based, tie stalls, or free stalls. This device has demonstrated that it can be used to estimate methane emissions in real time from sheep, cattle, and possibly other ruminants. Since the data are stored in the memory card, no samples are required to be immediately transferred to the lab, and data can be obtained quickly.

Although Chagunda and Yan (2011) revealed the positive outcomes of using LMD, the author also points out several challenges of using the technology. The first issue is extracting the methane emission data from the animal. Because ruminants are eructating methane from their mouths and respiring methane from

their nostrils, the laser beam on the LMD is only measuring one of these emissions at a time. To compensate for this issue, it is suggested that both are measured over longer durations. Unlike respiration chambers, the LMD does not account for the 5–10 % methane emitted from the rectum (Johnson and Johnson 1995). Taking the above issues into account and measuring methane emissions every hour for 24 h in conjunction with documenting the animals' activities, this technique could become labor intensive.

13.13 Intraruminal Gas Measurement Device

As an alternative to using SF_6 tracers or respiration chambers to estimate enteric methane emissions from cattle on pasture, an intraruminal gas measurement device has been developed at the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia. The proposed gas measurement device is capable of being housed in the rumen as it is impermeable to liquid and is swallowed by the ruminant as a bolus with a tubular body. When first swallowed, the device has wings that are held in position by dissolvable bands. Once in the stomach, the bands dissolve and the wings expand outward to prevent it from being expelled from the rumen. The bolus is permeable to gases and has gas sensors in the form of miniaturized infrared sensors that can detect the methane in the rumen. A controller is coupled to the gas sensor so that it can periodically process and output data that provides the amount of methane in the rumen (Wright et al. 2013). Although this device is not yet available, it is believed to be an alternative to the SF_6 tracers. The intra-stomach device is considered more desirable because it does not significantly impede the animal in its natural environment. Lastly, this device has an advantage in that it can be applied to a wide variety of ruminants (e.g., cattle, sheep, giraffes), while other methodologies are typically species specific.

13.14 Intergovernmental Panel on Climate Change (IPCC)

In 1988, the IPCC was created by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to act as an international body to assess climate change (IPCC 2007). To estimate enteric methane emissions, the IPCC uses three tiers: tier 1, 2, and 3. In general, tier 1 is a less accurate approach for determining enteric methane emissions from different regions of the world and does not take into account variations in animal physiology production level (Yan et al. 2006). Instead, it relies on a default emission factor given in the *IPCC Guidelines* that is multiplied by the number of animals for each livestock group to calculate the total methane emissions. In the United States, all livestock excluding cattle are part of tier 1, and a less detailed approach is taken in comparison to tier 2.

The tier 2 method is more accurate and is country specific for countries that have large cattle and sheep populations and have documented records of diet and animal populations. An appropriate methane emission factor is determined and multiplied by the number of animals for each animal type. To do this, animal population data and animal and feed characteristics are needed. The latter are obtained either from a government organization like the Environmental Protection Agency (EPA) or from interviews of key people in the industry. In the United States, the EPA developed the Cattle Enteric Fermentation Model (CEFM) that divides the cattle population into subcategories. For dairy cattle, subcategories include calves, replacement heifers, and cows, while beef cattle subcategories include steers, bulls, cows, feedlot cattle, and calves (EPA 2010). Along with the subcategories, the specific diets are also analyzed, and the COWPOLL ruminant digestion model evaluates the methane conversion rates (Y_m) from respiration chambers that represent the gross energy converted to methane (EPA 2010; Montanholi et al. 2008).

Tier 3 also uses the Y_m calculations, but is a more complex method than tier 2. To be part of the tier 3 method, there needs to be a scientific documentation in an article published in an international journal.

13.15 Conclusion

Several different methane estimation methodologies exist, and choosing which one to utilize is dependent upon various factors such as cost, maintenance, accuracy, or the environment in which the ruminant lives in. With these methane emission estimation methodologies present, it is possible to calculate how much methane an individual ruminant or a herd is producing under specific diets, by certain species, or breed. Although this chapter highlighted several strategies used to estimate methane emissions from ruminants, new methodologies or improvements on the present methodologies will be created. Each methodology has its own advantages and disadvantages that need to be considered before use in an experiment and after experimental data are retrieved and interpreted.

References

Bhatta R, Enishi O, Kurihara M (2007) Measurement of methane production from ruminants. Asian-Australas J Anim Sci 20:1305–1318

Chagunda M, Yan T (2011) Do methane measurements from a laser detector and an indirect open-circuit respiration calorimetric chamber agree sufficiently closely? Anim Feed Sci Technol 165:8–14

Chagunda M, Ross D, Roberts D (2009) On the use of a laser CH_4 detector in dairy cows. Comp Electron Agric 68:157–160

Chagunda M, Ross D, Rooke J, Yan T, Douglaus J-L, Poret L, McEwan N, Teeranavattanakul P, Roberts D (2013) Measurement of enteric methane from ruminants using a hand-held laser methane detector. Acta Agric Scand Sect A Anim Sci 63:68–75

Ellis J, Kebreab E, Odonto N, McBride B, Okine E, France J (2007) Prediction of methane production from dairy and beef cattle. J Dairy Sci 90:3456–3467

EPA (2010) Inventory of U.S. greenhouse gas emissions and sinks: 1990–2010: Ch. 6 Agriculture. U.S. Environmental Protection Agency, Washington, DC

EPA (2013) U.S. Environmental Protection Agency: ruminant livestock. In: Methane sources emiss. http://www.epa.gov/rlep/faq.html

Getachew G, Robinson P, DePeters E, Taylor S, Gisi D, Higginbotham G, Riordan T (2005) Methane production from commercial dairy rations estimated using an in vitro gas technique. Anim Feed Sci Technol 123:391–402

Global Methane Emissions and Mitigation Opportunities (2014) In: Global Methane Initiative. www.globalmethane.org/documents/analysis_fs_en.pdf

Grainger C, Clarke T, McGinn SM, Auldist MJ, Beauchemin KA, Hannah MC, Waghorn GC, Clark H, Eckard RJ (2007) Methane emissions from dairy cows measured using the sulfur hexafluoride (SF6) tracer and chamber techniques. J Dairy Sci 90:2755–2766

Huntington G, Cassady J, Gray K, Poore M, Whisnant S, Hansen G (2012) Use of digital infrared thermal imaging to assess feed efficiency in Angus bulls. Prof Anim Sci 28:166–172

IPCC (2007) Intergovernmental Panel on Climate Control Fourth Assessment Report. http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch15s15-3.html

Johnson K, Johnson D (1995) Methane emissions from cattle. J Anim Sci 73:2483–2492

Johnson K, Huyler M, Westberg H, Lamb B, Zlmmerman P (1994) Measurement of methane emissions from ruminant livestock using a SF6 tracer technique. Environ Sci Technol 28:359–362

Kelly JM, Kerrigant B, Milligan LP, Mcbride BW (1994) Development of a mobile, open-circuit indirect calorimetry system. Can J Anim Sci 74:65–71

Lee H, Lee S, Kim J, Oh Y, Kim B, Kim C, Kim K (2003) Methane production potential of feed ingredients as measured by in vitro gas test. Asian-Australas J Anim Sci 16:1143–1150

Lockyer D, Champion R (2001) Methane production by sheep in relation to temporal changes in grazing behaviour. Agric Ecosyst Environ 86:237–246

Lockyer D, Jarvis S (1995) The measurement of methane losses from grazing animals. Environ Pollut 90:383–390

Madsen J, Bjerg BS, Hvelplund T, Weisbjerg MR, Lund P (2010) Methane and carbon dioxide ratio in excreted air for quantification of the methane production from ruminants. Livest Sci 129:223–227

Mauricio RM, Mould FL, Dhanoa MS, Owen E, Channa KS, Theodorou MK (1999) A semi-automated in vitro gas production technique for ruminant feedstuff evaluation. Anim Feed Sci Technol 79:321–330

McClean J, Tobin G (1987) Animal and human calorimetry. Cambridge University Press, Cambridge

McGinn S, Beauchemin K, Iwaasa K, McAllister A (2006) Assessment of the sulfur hexafluoride tracer technique for measuring enteric methane emissions from cattle. J Environ Qual 35:1686–1691

Menke K, Raab L, Salewski A, Steingass H, Fritz D, Schneider W (1979) The estimation of the digestibility and metabolizable energy content of ruminant feeding-

stuffs from the gas production when they are incubated with rumen liquor in vitro. J Agric Sci 93:217–222

Miller W, Koes R (1988) Construction and operation of an open-circuit indirect calorimetry system for small ruminants. J Anim Sci 66:1042–1047

Montanholi Y, Schenkel F, Miller S, Swanson K, Mandell I (2006) Infrared images taken in beef cows: repeatability of the measurements. In: Proceedings of the eighth world congress on genetics applied to livestock production

Montanholi Y, Swanson K, Miller S, Palme R, Schenkel F (2007) Relationship between residual feed intake and infrared thermography and glucocorticoid levels in feedlot steers from three different sire breeds. In: Proceedings of the Canadian Nutrition Congress, p 36

Montanholi YR, Odongo NE, Swanson KC, Schenkel FS, McBride BW, Miller SP (2008) Application of infrared thermography as an indicator of heat and methane production and its use in the study of skin temperature in response to physiological events in dairy cattle (*Bos taurus*). J Therm Biol 33:468–475

Murray R, Bryant A, Leng R (1976) Rates of production of methane in rumen and large-intestine of sheep. Br J Nutr 36:1–14

Odongo NE, AlZahal O, Las JE, Kramer A, Kerrigan B, Kebreab E, France J, McBride BW (2008) Data capture: development of a mobile open-circuit ventilated hood system for measuring real-time gaseous emissions in cattle. In: France J, Kebreab E (eds) Mathematical modeling in animal nutrition. CABI Publishing, Wallingford, pp 225–240

Ørskov ER, Flatt WP, Moe PW (1968) Fermentation balance approach to estimate extent of fermentation and efficiency of volatile fatty acid formation in ruminants. J Dairy Sci 51:1429–1435

Pell A, Schofield P (1993) Computerized monitoring of gas production to measure forage digestion in vitro. J Dairy Sci 76:1063–1073

Pinares-Patiño CS, Clark H (2008) Reliability of the sulfur hexafluoride tracer technique for methane emission measurement from individual animals: an overview. Aust J Exp Agric 48:223

Pinares-Patiño C, Holmes C, Lassey K, Ulyatt M (2008) Measurement of methane emissions from sheep by sulphur hexafluoride tracer technique and by the calorimetric chamber: failure and success. Animal 2:141–148

Place SE, Pan Y, Zhao Y, Mitloehner FM (2011) Construction and operation of a ventilated hood system for measuring greenhouse gas and volatile organic compound emissions from cattle. Animals 1:433–446

Poikalainen V, Praks J, Veermae I, Kokin E (2012) Infrared temperature patterns of cow's body as an indicator for health control at precision cattle farming. Agron Res 10:187–194

Sheppard J, Westberg H, Hopper J, Ganesan K, Zimmerman P (1982) Inventory of global methane sources and their production rates. J Geophys Res 87:1305–1312

Storm I, Hellwing ALF, Nielson NI, Madsen J (2012) Methods for measuring and estimating methane emission from ruminants. Animals 2:160–183

Tedeschi LO, Schofield P, Pell AN (2008) Determining feed quality for ruminants using in vitro gas production technique. Evaluating different models to assess gas production measurements. Fourth Work. Model Rumin Nutr Juiz de Fora 1–15

Turner H, Thorton R (1966) A respiration camber for cattle. Proc Aust Soc Anim Prod 6:413–419

Waghorn G, Garnet E, Pinares-Patiño C, Zimmerman S (2013) Implementation of GreenFeed for estimating methane in a dairy herd grazing pasture. Greenhouse gases from animal agriculture conference, Dublin, p 80

Wilkins J (1974) Pressure transducer method for measuring gas production by microorganisms. Appl Microbiol 27:135–140

Williams YJ, Popovski S, Rea SM, Skillman LC, Toovey AF, Northwood KS, Wright A-DG (2009) A vaccine against rumen methanogens can alter the composition of archaeal populations. Appl Environ Microbiol 75:1860–1866

Wolin MJ (1960) A theoretical rumen fermentation balance. J Dairy Sci 43:1452–1459

Wright A-DG, Kennedy P, O'Neill C, Toovey A, Popovski S, Rea S, Pimm C, Klein L (2004) Reducing methane emissions in sheep by immunization against rumen methanogens. Vaccine 22:3976–3985

Wright A-DG, Ellis K, Dempsey J, Overs L, Valencia P, Paull D, McSweeney C (2013) System, method, and device for measuring a gas in the stomach of a mammal. World Intellectual Property Organization. Patent: WO 2013/003892 A1

Yan T, Mayne C, Porter M (2006) Effects of dietary and animal factors on methane production in dairy cows offered grass silage based diets. Int Congr Ser 1293:123–126

Zimmerman P (1993) Measuring metabolic gas emissions from animals. US Patent 5,265,618, 30 Dec 1993