

Characterizing Resonance Scaling in Cattle Eructation Sounds for Methane Emission Estimation

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Summary:

We propose an acoustic method for estimating methane emissions from cattle eructation sounds, based on resonance scaling caused by changes in gas molecular weight. To evaluate this method, we reproduced eructation sounds experimentally and extracted resonance-related components using cepstral analysis. The lifted spectra for N₂ and CO₂ showed similar shapes after frequency scaling, suggesting that the gas molecular weight can be estimated with a 2.9% error.

Keywords: Acoustic sensing, Resonance scaling, Cattle, Eructation sounds, Wearable device

Introduction

Methane emissions from cattle and other livestock are a significant source of global warming. Although methane-reducing feeds have been developed, their effects vary among individual cattle and over time [1]. Therefore, long-term monitoring of methane emissions is required. However, existing methods, such as chamber method and sniffing systems, are not suitable for long-term, continuous monitoring of total methane emissions from cattle [2]. We focused on an acoustic approach. Body-transmitted sounds in animals can be measured, and collar-mounted devices have been shown to monitor heart sounds, scratching sounds, and eructation sounds in cattle [3].

We investigate an acoustic method for long-term monitoring of total methane emissions from cattle using eructation sounds. However, it is unclear whether gas molecular weight can be reliably estimated from eructation sounds. In this study, we therefore aim to evaluate the measurement performance of the proposed method by experimentally reproducing resonant sounds in the esophagus of cattle.

Materials and Methods

Figure 1 shows the concept of the proposed method. A collar-mounted device equipped with body-conduction microphones is attached to cattle to measure eructation sounds generated in the esophagus.

Eructation sounds are considered to follow the source-filter theory: sound source generated at the esophageal groove is filtered through the resonance characteristics determined by the

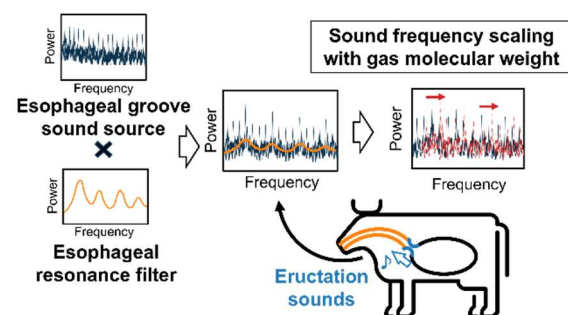


Fig. 1. Concept of methane emission measurement from eructation sound.

concentration alter the molecular weight of the eructated gas, thereby changing the speed of sound and scaling the resonance frequencies. Since the sound velocity c is given by eq. (1) using the specific heat ratio k , gas constant R , absolute temperature T , and molecular weight M , the average molecular weight of the gas can be estimated from the frequency scaling.

$$c = \sqrt{\frac{kRT}{M}} \quad (1)$$

Figure 2 shows the experimental setup used to reproduce eructation sounds under different gas. Since eructation sounds generated in the cattle esophagus occur through a mechanism similar to human phonation, a vocal-tract model was used in this experiment. CO₂ and N₂ were used as test gases. A slit silicone structure was used as an artificial vocal fold [4], and the vocal tract was modeled as an open-ended resonator. The sound was measured using an omnidirectional microphone (Onosokki, MI-1271). The recorded

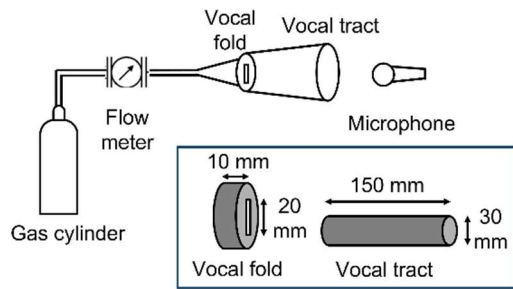


Fig. 2. Experimental system.

sound data were analyzed to obtain the power spectrum and liftered spectrum.

Results and Discussion

Figure 3 shows the power spectrum and liftered spectrum for CO₂ and N₂. The power spectra show both peaks corresponding to the sound source and a spectral pattern associated with resonance characteristics. The liftered spectrum represents the spectral envelope of the power spectrum and can be regarded as extracts the resonance-related component. The peak points of each liftered spectrum are also indicated.

Figure 4 shows a comparison of the corresponding peak frequencies in the liftered spectra of N₂ and CO₂. Averaging the first five peaks of the liftered spectra showed that the CO₂ peak frequencies were 0.78 times those of N₂. The theoretical frequency ratio is expressed by eq. (2), indicating that gas molecular weight could be estimated with an error of 2.9% (absolute error: 1.27)

$$\frac{f_{CO_2}}{f_{N_2}} = \sqrt{\frac{k_{CO_2} \cdot M_{N_2}}{k_{N_2} \cdot M_{CO_2}}} = \sqrt{\frac{1.30 \cdot 28}{1.40 \cdot 44}} \approx 0.77 \quad (2)$$

The observed error may be attributed to the mixing of air ($M = 29$) in the resonant tube.

Conclusion

In this study, we experimentally reproduced eructation sounds and evaluated an acoustic method for gas molecular-weight estimation based on resonance scaling. The liftered spectra of N₂ and CO₂ showed similar patterns after frequency scaling, suggesting that the gas molecular weight can be estimated with a 2.9% error. Future work will focus on experiments using geometries closer to the cattle esophagus, evaluating measurement accuracy for various molecular weights, and investigating acoustic changes during propagation through body tissues.

References

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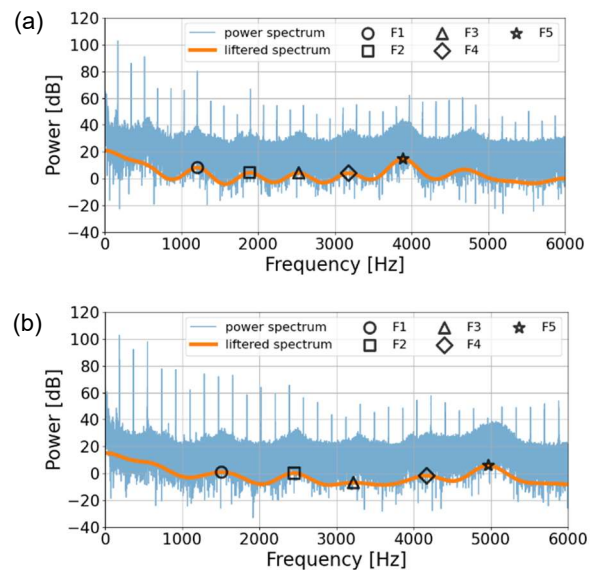


Fig. 3. Power spectrum and liftered spectrum for (a) CO₂ and (b) N₂

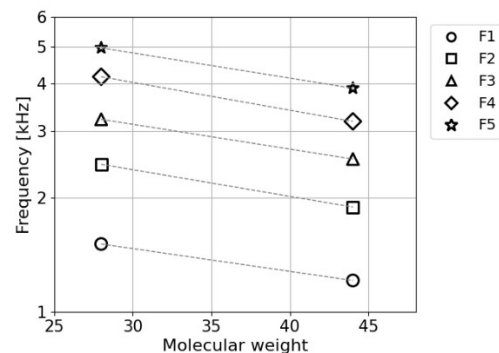


Fig. 4. Comparison of the corresponding peak frequencies in the liftered spectra of N₂ and CO₂.

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