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Molecular weight measurement of cattle-emitted gases using whistle acoustic signals

Michitaka Yamamoto[1], Rinka Yoshioka[1], Seiichi Takamatsu[1], Toshihiro Itoh[1]
[1] Department of Precision Engineering, Graduate School of Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku 113-8656, Tokyo, Japan

Corresponding Author's e-mail address: yamamoto-michitaka@g.ecc.u-tokyo.ac.jp

Summary:

We experimentally revealed that the effect of temperature can theoretically be compensated in our proposed measurement method of the molecular weight of gas using whistles. The effect of temperature change on the molecular weight was around 0.03/°C, which is almost consistent with the theory. Furthermore, gas measurement with unknown molecular weight collected from cattle rumen fluid was demonstrated, with a molecular weight resolution of at least less than 1.5.

Keywords: sound and acoustic, gas sensor, molecular weight, Whistle, cattle

Introduction

There has been an increasing demand for simple measurement methods of gases; methane gas emitted by cattle has attracted much attention as a cause of global warming, and a simple method for measuring exhaled gas is required.

Recently, simple gas measurement methods based on acoustic signals have been proposed: the detection of hydrogen leakage by acoustic signals [1] and the detection of oxygen gas concentration [2]. The average molecular weight of gas changes when hydrogen leaks or oxygen concentration changes, which results in the change of sound velocity and resonant frequency of acoustic sound.

We're also developing a new sensing method to measure gas molecular weight using acoustic signals from two whistles [3][4]. Previous studies have demonstrated the basic principles and fundamental experimental results; however, they have not evaluated the impact of temperature [3],[4]. It remains uncertain whether temperature has only a negligible influence on these characteristics, or if other factors, such as changes in the whistle's characteristics with varying temperatures, might also play a role in the observed outcomes. In this paper, we experimentally evaluated the effect of temperature. Furthermore, gas measurement of unknown molecular weight was tested using gases from cattle rumen fluid.

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Sensing mechanism [3][4]

The proposed sensing mechanism of gas molecular weight using whistles is shown in Fig. 1. The fundamental frequency f when gas flows into the whistle can be expressed by the following:

$$f = a\sqrt{\frac{kRT}{M}} + bQ + c \qquad (1)$$

where M, Q, and T are the molecular weight, flow rate, and temperature of the gas, respectively, and k and R are the specific heat ratio and gas constant. The a is a whistle-specific constant, and the b and c are constants determined by the type and combination of whistles. The gas's molecular weight and flow rate can be calculated from each whistle's multiple frequency measurement results.

From above equation, changes in temperature are expected to be theoretically calculated. However, temperature T may affect the specific heat ratio K and the properties of the whistles themselves and cause further errors. Therefore, we will attempt to evaluate the experimental effect of temperature T on this study.

Experiment methods

The shapes of the whistles used in this study are shown in Fig. 2. Two whistles with different sizes

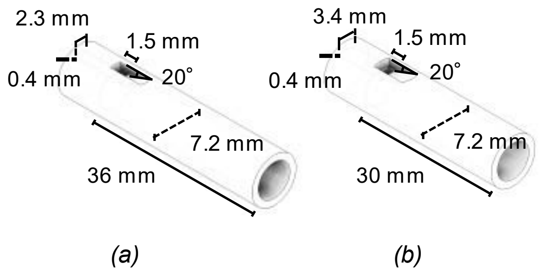

Fig. 2. The images of the used two whistles. (a) Whistle 1, (b) Whistle 2.

were fabricated by a 3D printer (Keyence Corporation, Agilista) using acrylic UV curable resin (Keyence Corporation, AR-M2).

The frequency shift by temperature was evaluated by inserting two types of gases (N_2: molecular weight 28 and CO_2: molecular weight 44) with different temperatures from 22 to 28°C to each whistle. The sounds generated by the whistles were measured by a microphone (Ono Sokki Co., Ltd., MI-1271), and fundamental frequency was obtained.

As a demonstration, we also attempted to gas measurement of unknown molecular weight. With cattle breath analysis in mind, the molecular weight of the gas generated from cattle rumen fluid was collected and measured using the proposed method. For reference, the gas was also measured by using gas chromatograph (SHIMADZU CORPORATION, GC-2014) to know the actual molecular weight.

Experimental results

Figure 3 shows the effect of the temperature on each whistle in the case of measuring N_2 gas. It shows that the frequency is almost linear with the change in temperature, meaning that the effect of temperature is expected to be theoretically calculated. Because the experiment was conducted using plastic materials, which are considered susceptible to thermal effects, it seems that there is a theoretical possibility of compensating for temperature.

Noted that a change of 1 °C in temperature (which corresponds to an approximate 0.03 change in sqrt(T)) means that the frequency changes by 2-3 Hz/°C. It corresponds to the molecular weight change of around 0.03/°C, almost consistent with the theory. Though improvement of the accuracy to the molecular weight is the first requirement because it is still around 0.45 [4], theoretical temperature compensation is needed for accuracy measurement in the future

Figure 4 shows the measurement result of unknown gas generated from rumen liquid. The molecular weight error was at least less than 1.5. We intend to enhance the sensitivity further by refining the whistle in future experiments.

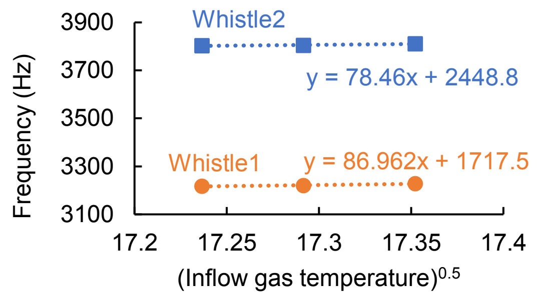

Fig. 3. Effect of temperature on the fundamental frequency of each whistle in case of N_2 gas.

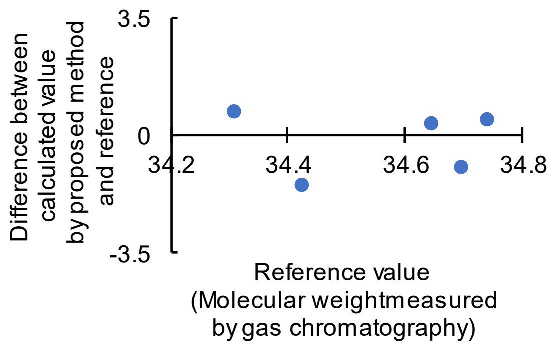

Fig. 4. The measurement result of unknown gas collected from rumen liquid.

Conclusions

We revealed that the effect of temperature can theoretically compensated in the proposed measurement method of the molecular weight of gas using whistles. The effect of temperature on the molecular weight was around 0.03/°C, which almost consistent with the theory. Furthermore, measurement of gas with unknown molecular weight was demonstrated, and the molecular weight resolution was at least less than 1.5. Noted that the sensitivity could be further improved by improving the measurement system and the whistle.

Acknowledgments

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