Least Square Method for Measuring $^{13}CO_2$ Content in Exhaled Air Using Laser Absorption Spectroscopy

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The Tunable Diode Laser Absorption Spectroscopy (TDLAS) method, in which tunable diode lasers (TDL) are used as radiation sources, is widely used in various gas analysis problems [1]. In particular, this method has been successfully used for measuring the CO2 content, including $^{13}CO_2$ mixed with $^{12}CO_2$ in exhaled air during respiratory tests in the non-invasive diagnosis of gastrointestinal cancer. Thus one of the most promising spectral bands from the detection sensitivity perspective is $^{13}CO_2$, and the measurement accuracy is the region near the wavelength of 2 microns, including a number of vibrational-rotational absorption lines of the $^{13}CO_2$ minimally overlapping with the 12CO2 vibrational-rotational lines [2-4].

A number of digital adaptive and non-adaptive methods (filtering algorithms), such as Fast Fourier Transform (FFT), Kalman, Savitsky-Golay (SG) and Wiener filters, and Empirical Mode Decomposition Algorithm (EMD), have been used in many works while processing experimental signals in order to reduce noise.

Another filtering algorithm is the least square method (LSM), which was also used in a number of works for experimental signal processing. Thus, for example, this method has been used in the hydrogen sulfide content in the natural gas measurement problem. LSM was implemented for propane-butane gas mixtures analysis [5].

In this work, the authors report on the implementation of LSM for processing an experimental signal obtained by TDLAS using TDL emitting near a wavelength of 2 microns in order to improve the $^{13}CO_2$ content online measurement accuracy in exhaled air.

The signal obtained earlier was utilised as the experimental signal, processed in previous works using the FFT filter and EMD algorithm [2], Kalman [3] and Wiener [4] filters.

The TDL of $\sim$1 mW power with the frequency tuning range of 4860 - 4880 cm-1 has been used. The multi-pass cell was filled with exhaled air samples of the total $^{12}CO_2$ and $^{13}CO_2$ fraction from 1.5 to 3.5% with concentrations ratios of $^{12}CO_2$ and $^{13}CO_2$ in the range from 70 to 140. It was possible to change the total pressure in the cell from atmospheric to 10 mbar. The laser radiation, transmitted through the gas cell, was recorded by an infrared photoelectric detector, the signal from which was processed using an analogue-to-digital converter (ADC).

The $^{13}CO_2$ molecule P(12) absorption line, which is extremely far from the neighbouring absorption lines R(32) and R(34) of the $^{12}C^{16}O_2$ molecule (spectral range 4876.54879 cm^{-1}). It has been established by the studies conducted in this research work that using the 2nd order Least Square Method for processing the experimental signal obtained by the TDLAS method is an effective tool for improving the $^{13}CO_2$ content measurement accuracy in exhaled air along with the filtering algorithms studied earlier. The measurement accuracy reached is significantly lower than 1%, which meets the requirements for breathing tests.

References

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