Selection of the optimal combination of water vapor absorption lines for detection of temperature in combustion zones of mixing supersonic gas flows by diode laser absorption spectrometry

V.R. Mironenko[*], Yu.A. Kuritsyn, M.A. Bolshov, V.V. Liger

Institute for Spectroscopy RAS, 108840 Troitsk, Moscow, Russia

Abstract. Determination of a gas medium temperature by diode laser absorption spectrometry (DLAS) is based on the measurement of integral intensities of the absorption lines of a test molecule (generally water vapor molecule). In case of local thermodynamic equilibrium temperature is inferred from the ratio of the integral intensities of two lines with different low energy levels. For the total gas pressure above 1 atm the absorption lines are broadened and one cannot find isolated well resolved water vapor absorption lines within relatively narrow spectral interval of fast diode laser (DL) tuning range (about 3 cm⁻¹). For diagnostics of a gas object in the case of high temperature and pressure DLAS technique can be realized with two diode lasers working in different spectral regions with strong absorption lines. In such situation the criteria of the optimal line selection differs significantly from the case of narrow lines. These criteria are discussed in our work. The software for selection the optimal spectral regions using the HITRAN-2012 and HITEMP data bases is developed. The program selects spectral regions of DL tuning, minimizing the error of temperature determination $\delta T/T$, basing on the attainable experimental error of line intensity measurement δS. Two combinations of optimal spectral regions were selected – (1.392 & 1.343 μm) and (1.392 & 1.339 μm). Different algorithms of experimental data processing are discussed.

We shall consider the problem on errors in evaluation of temperature [1-3]. It is possible to show, that a systematic error in evaluation of temperature

$$\frac{\Delta T}{T} = \frac{T}{T_{eff}} \frac{\Delta R}{R} = \frac{T}{T_{eff}} (\frac{1}{S_1} + \frac{1}{S_2})^{1/2} \Delta S, \tag{1}$$

where $T_{eff} = \dfrac{hc\Delta E''}{k}$, $R = \dfrac{S_2}{S_1}$.

The error ΔT is proportional to T^2/T_{eff} and depends on relative errors in line strengths S_1 and

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[*] Corresponding author: miron@isan.troitsk.ru

S_2 of the transitions. In turn, these errors are determined by an inaccuracy of the parameters in data bases, experimental measuring errors and methodical errors of data processing.

Besides the above mentioned errors of ΔT, there are the errors caused by noise in system (statistical errors). By analogy with (1), the expression for statistical error of evaluation of temperature (in the conjecture of independence and equality of statistical errors $\delta S_1 = \delta S_2 = \delta S$) can be written in the form:

$$\delta T = \frac{T^2}{T_{eff}}(\frac{1}{S_1^2} + \frac{1}{S_2^2})^{1/2}\delta S = \frac{T^2}{T_{eff}}(\frac{1}{S_1^2} + \frac{1}{S_2^2})^{1/2}\frac{\delta A}{NL}. \tag{2}$$

In (2) we used, that statistical error in measurements of line strength S of a transition is connected with an error in measurement of the integral absorption A of line in the form: $\delta S = \delta A/NL$. In a probing volume with total pressure P and relative density of molecules χ, $N = \chi P/kT$ and

$$\delta T = \frac{kT^3}{T_{eff}\chi PL}(\frac{1}{S_1^2} + \frac{1}{S_2^2})^{1/2}\delta A = \frac{kT^3}{T_{eff}\chi PL}(1 + R^2)^{1/2}\frac{\delta A}{S_1}. \tag{3}$$

Under the designed program two optimum combinations of spectral regions have been selected:

Combination 1: "cold" $\lambda = 1.392$ μm ($\nu = 7184 - 7187$ cm^{-1}), "hot" $\lambda = 1.343$ μm ($\nu = 7443 - 7446$ cm^{-1}):

Combination 2: "cold" $\lambda = 1.392$ μm ($\nu = 7184 - 7187$ cm^{-1}), "hot" $\lambda = 1.339$ μm ($\nu = 7465 - 7468$ cm^{-1}).

Calculated dependences of S and δT for two combinations over the temperature range 500 – 2000 K, expected in experiment are presented in the Figure. It is evident, that both combinations can be used for measuring temperature in a whole temperature range 500 – 2000 K, however the combination *1* ensures more precise evaluation of temperature over the range 500 – 1600 K, and the combination *2* – over the range 1600 – 2000 K, because the lines in spectral region $\nu = 7465 - 7468$ cm^{-1} start from "hotter" lower levels.
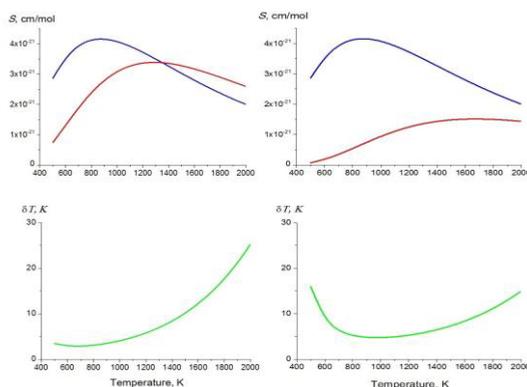

Fig. 1. Line strengths (the upper graphs) and errors of evaluation of temperature (the lower graphs) for two combinations of lines: the combination 1 (the left graphs), the combination 2 (the right graphs). Blue color is used for designation of "cold" lines, red color – for "hot" lines.

References

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