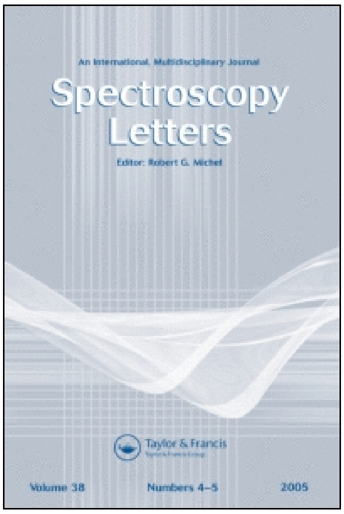

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Flame Temperature Remote Determination from Spectrometry Based on Fiber Optics

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FLAME TEMPERATURE REMOTE DETERMINATION FROM SPECTROMETRY BASED ON FIBER OPTICS[1]

Key Words: Fiber Optics; Two–Line Method; Flame Temperature; Spectrometry

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Abstract

The mode using the two–line method based on fiber optics to measure flame temperature by a rapid–scanning spectrometer is presented.The measurement system developed by us useful for remote measurement or to carry an optical signal in and out of environments like too low or too high temperatures, high magnetic field etc. is described in detail. The technique is discussed and compared with other methods in flame spectroscopy. Our results show that the advantages of this method are very sensitive, flexible, rapid, convenient and accurate. The further applications such as using the method in automation design or process automation are also discussed.

Introduction

The temperature determination by spectroscopical method for hot gases like flames has long been discussed by spectroscopists. The method of estimating temperature using remote Fourier transform infrared emis-

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sion or absorption spectra is one of the best methods reported recently[1-4] ; however, the method by Fourier transform infrared (FT–IR) spectra is only for measuring rotation–vibration spectra of diatomic molecules or multimolecular. Therefore, the temperature measurement method using flame atomic spectroscopy remains one of the most useful method. Till now the sodium line reversal method[5]and the modified sodium line reversal method[6]have still been considered as the best and most extensively used methods. Although these methods possess many advantages in determining flame temperature, they also have their own shortcomings. For example, the sodium line reversal method is slow and complicated, while both the sodium line reversal method and the modified sodium line reversal method all need the calibrated lamp as reference source which limits the attainable precision and the highest temperature measured because of its own highest temperature of the calibrated lamp. Furthermore, the necessity of intricate optical arrangements would complicate the use of those classical spectroscopic methods. Based on these considerations, the two–line method based on fiber optics using spectrometer is developed by us to determine the flame temperature rapidly, conveniently and accurately.

Instead of complex optical arrangements used previously this method uses optical fibers to carry signals directly from hot gases, such as flames, to the entrance slit of the rapid–scanning monochromator used in this work to analyze and then record. Furthermore, the present type of spectrometry needs no cabibrated lamp as the reference source, which not only simplifies optical system but also improves analysis precision.

While the experimental system has many advantages, such as high collection efficiency and ease of operation ,it is also flexible and convenient to be used to supervise many different locations simultaneously. To maximize safety considerations for both equipment and personnel this measurement system can be used for remote analysis and exploration of small volumes or closed systems. Recent developments in fiberoptics, electronics and computers make it possible to use this method as one of the most important ways to realize automation design or process automation in various fields.

In our experiments the temperature distribution in different locations of flames is determined through a rapid–scanning spectrometer based on fiberoptics using the two–line method. The result of this novel method is compared with other temperature measurement methods, which shows that the estimated temperature by this mode is in remarkably good agreement with the temperature measured by other methods. The present method possess the advantages including convenience, accuracy, flexibility and rapidity.

Theoretical Principle

This method is based on the determination of integrated line intensities for transitions between different energy levels of the thermometric species when self–absorption could be neglected.

The expression for the light intensity of the radiance emitted in a spectral source characterized by local thermal equilibrium is generally given by the differential equation

$$I_{(em)} = \int_{\Delta\nu_{qp}} d\nu \int_0^l dx \, [\frac{1}{4\pi} A_{qp} h\nu \, n_q P(\nu)] \, exp \, [-\int_0^x dx' K(\nu)] \qquad (1)$$

where $$K(\nu) = \frac{h\nu}{c}(I_{pq} n_p - I_{qp} n_q) P(\nu) \qquad (2)$$

and l——length of the optical path

A_{qp},$I_{qp}$and I_{pq}——spontaneous emisson, induced emission and induced absorption transition probability coefficients.

n_q,n_p——particle density in the upper and lower quantum states of the transition.

$P(\nu)$——line shape function.

$\Delta \nu_{qp}$——total width of the spectral line.

h——Planck constant.

c——speed of light.

In the absence of self–absorption effects, from Eqns (1) and (2) we have

$$I_{(em)} = \int_{\Delta\nu_{qp}} d\nu \int_0^l dx \, [\frac{1}{4\pi} A_{qp} h\nu n_q P(\nu)]$$

According to the Maxwell–Boltzmann distribution, when $v \approx v_0$, using the two–line wavelength spectra, from Eqn (3) we can obtain the resulting expression[7]

$$T = \frac{(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}) \cdot const}{log(\frac{I_1}{I_2}) - log(\frac{A_{\lambda_2}}{A_{\lambda_1}}) - \frac{1}{2}log(\frac{f_1}{f_2}) - \frac{1}{2}log(\frac{r_1}{r_2}) - 3log(\frac{\lambda_2}{\lambda_1})} \quad (4)$$

where const is 0.6245 cm • K.

and λ——wavelength of the spectral line.

A_{λ_1}, A_{λ_2} ——instrument response coefficient corresponding to characteristic wave lengths λ_1 and λ_2, respectively.

r_1 / r_2——damping constant.

f_1, f_2——oscillator strength .

Therefore, the flame temperature T could be estimated from Eqn (4) once the instrument response coefficients corresponding to characteristic wavelengths and the spectral line intensities are determined.

Experimental

The block diagram of the measurement system of this method is shown in Fig.1.

The monochromator used in this work is model HRD–1 double grating monochromator manufactured by Jobin–Yvon which possesses two complete Czerny–Turner mounting units whose linear reciprocal dispersion is 6.6 Å / mm. The plastic fibers used to transport light of some characteristic wavelengths in the experiments have a core diameter of 1mm and the total length of about 10m. The flame is an alcoholic jet situated far away from the main spectrometer.The detector of this spectrometer is the photomultiplier R374 made by HAMAMATSU in Japan.

In the experimental system we used a rapid–scanning UV–VIS monochromator based on optical fibers which transport light of characteristic wavelengths emitted by some particular lines natural or added in the flame set up arbitrarily that is imaged directly into the spectrometer where analysis of light intensity against wavelength takes place. This mode needs no calibrated standard tungsten ribbon lamp as reference source while complex arrangements of lenses and mirrors used previously are replaced by the optical fiber which makes the present spectrometry cost–effective, flexible and convenient.

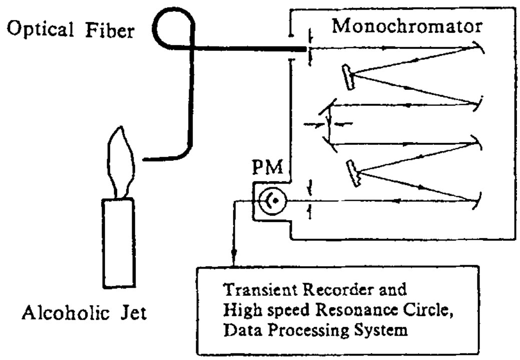

Fig.1. Block diagram of the measurement system of this method

Table I . The results determined by this method and compared with other methods

Methods / Temperature,K / Location of flame	This method	Sodium line reversal method	Modified sodium line reversal method
Situation 1	1711.8	1729.4	1723.0
Situation 2	1830.0	1844.1	1848.0

Table II . Precision of this mode in comparision to other spectroscopical methods

Location of flame	Situation 1			Situation 2		
Methods	this work	Na–line reversal method	Modified Na–line reversal method	this work	Na–line reversal method	Modified Na–line reversal method
Standard deviations (n = 10 times)	11.2	5.5	15.5	18.0	5.0	22.1
Relative standard deviations (R.S.D)	0.7	0.3	0.9	1.0	0.3	1.2

Results and Discussion

In our experiments the solution of potassium salt is induced into the flame so that two spectral lines of potassium whose characteristic wavelengths are 4044.14Å and 7664.9 Å ,respectively, are used to determine the flame temperature.

First of all, the instrument response coefficient corresponding to characteristic wavelengths of the two spectral lines of potassium is calibrated by us since they are far away from each other. If $\lambda_1 = 7664.9$ Å and $\lambda_2 = 4044.14$Å, the ratio of the calibrated values $A_{\lambda_1} / A_{\lambda_2}$ is 7.4.

The results determined by this method and compared with other methods are shown in **Table** Ⅰ and **Table** Ⅱ.

Conclusions

1. From **Table** Ⅰ and **Table** Ⅱ, it can be seen that the flame temperature remote determination from spectrometry using the two–line method based on fiber optics agrees fairly with other spectroscopic methods.

2. While utilizing this mode to measure temperature of hot gases like flames, we should notice if characteristic wavelengths of the two chosen spectral lines were nearby each other (such as those of the two sodium lines, i.e., 5890 Å and 5896 Å) the instrument response coefficient corresponding to wavelength could be considered as equal value; otherwise, the instrument response must be calibrated.

3. The experimental system of this mode is simple, flexible and convenient. The advantages of this method are rapid, cost–effective, accurate and flexible.

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