

Film Thickness Compensation for Dual-Wavelength Dye-Film CO₂ Monitor

Yu Guangyun

(College of Mathematics and Computer Science, Nanjing Normal University, 210042 Nanjing, PRC)

Abstract: The paper introduces a compensation algorithm to be used to compensate the thickness differences of the dye indicator films in Dual-Wavelength Dye-Film CO₂ Monitors. With a series of experiments made, the test results show that the compensation algorithm works satisfactorily.

Key words: measurement of CO₂ concentration, dual-wavelength, dye indicator film, thickness compensation

CLC number: O652.2, **Document code:** B, **Article ID:** 1672-1292(2003)03-0008-03

1 Introduction

The sensor used in this instrument is an acid-base indicator dye, which acts as a completely reversible and non-consumable sensor. The indicator dye is produced in the form of thin, transparent film coated on the glass disk. The film is completely insoluble in water and contains nonvolatile composition; therefore it can function properly at the worksite with a wide range of temperature and relative humidity. The original color of the dye-film is light blue. It will become yellow when exposed to CO₂, and the shades of yellow color will increase with the increase of the concentration of the CO₂, making more and more yellow light go through the film. Consequently, while the yellow light I_{in} illuminates the dye-film from left side, as shown in Fig. 1, the measured yellow light I_{out} going out of the right side will show the CO₂ concentration around the dye-film.

However the dye-film cannot be produced in the same thickness, no matter what coating technique is employed. If the CO₂ concentration is the same, the transmitted yellow signal will vary with the thickness of the dye-film. The experimental result is shown in Fig. 2.

To obtain accurate measurement of the CO₂ concentration by using dye-film sensor, a compensation technique for the film thickness must be adopted.

2 Principle of compensation

The absorption spectrum of the dye indicator is shown in Fig. 3, which indicates that there is an absorption peak around 570 nm and a platform from 700 to 900 nm for CO₂, so that the dye indicator CO₂ sensor consists of two LEDs and one photodetector. One LED emits yellow light at around 570 nm, the other LED emits infrared light at

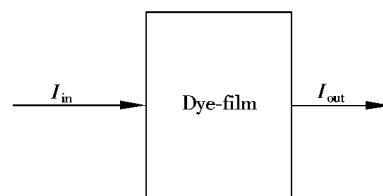


Fig 1 Dye-film sensor

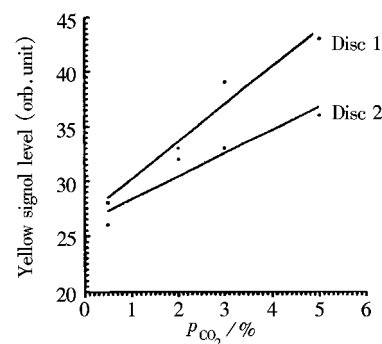


Fig. 2 The effect of the film thickness

Receipt date: 2003-03-10.

Biographical Notes: Yu Guangyun, male, born in 1944, associate professor, working on the research and application of computer control and intelligent instrument.

around 880 nm. The light from the sources is guided via a glass rod to illuminate the dye indicator film coated on the glass disc, with the transmitted light from the dye-film to be detected by the photodetector. The optical transmission property of the sensor can be described with a simple model shown in Fig. 4, where t stands for the thickness of the dye indicator film and d the length of effective optical path.

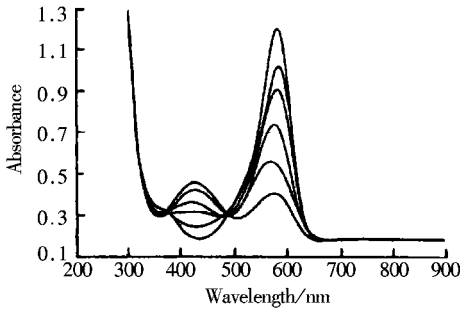


Fig. 3 The absorption spectrum of the dye indicator films

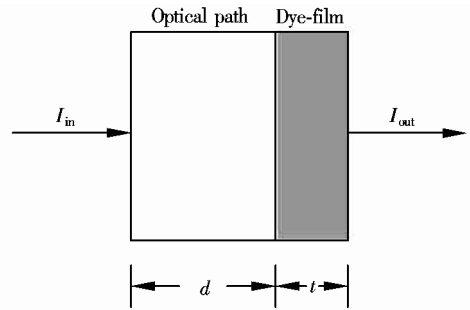


Fig. 4 Light transmission model of the sensor

The transmitted optical intensity of the light is affected by the absorption of the dye indicator film and the inserting loss in the optical path. The absorption property of the dye indicator film depends upon its composition and is different in various wavelengths. The inserting loss in the optical path depends mainly upon the optical alignment and moisture condensation and is assumed to be the same for both the yellow and the infrared wavelengths. Based on these assumptions and the Lambert-Beer Law, the light transmission can be described as follows:

$$I_{ir} = I_{iro} \text{EXP}[-A_d - a_{ir}t] \quad (1)$$

$$I_y = I_{yo}[-A_d - a_y(p_{CO_2})t] \quad (2)$$

Where I_{ir} : optical intensity of transmitted infrared light

I_y : optical intensity of transmitted yellow light

I_{iro} : optical intensity of incident infrared light

I_{yo} : optical intensity of incident yellow light

A : equivalent absorption coefficient caused by inserting loss in the optical path

a_{ir} : absorption coefficient of the dye indicator film at infrared wavelength

$a_y(p_{CO_2})$: absorption coefficient of the dye indicator film at yellow wavelength which is the function of the ambient p_{CO_2} level. At the range of p_{CO_2} less than 5%, the response of the dye is linear, thus $a_y(p_{CO_2})$ can be described as follows:

$$a_y(p_{CO_2}) = b_0 + b_1 p_{CO_2} \quad (3)$$

Suppose the inserting loss is negligible compared with the absorption induced by the variation in the dye-film thickness, equation 1 and 2 will become:

$$I_{ir} = I_{iro} \text{EXP}[-a_{ir}t] \quad (4)$$

$$I_y = I_{yo}[-a_y(p_{CO_2})t] \quad (5)$$

Combing equ. 4 with equ. 5 the following equation can be got:

$$a_y(p_{CO_2}) = a_{ir} [\text{Ln}(I_y/I_{yo}) / \text{Ln}(I_{ir}/I_{iro})] \quad (6)$$

From equation 6 it can be obtained that the absorption coefficient at the yellow wavelength is the function of the normalized yellow light and infrared light as well as the absorption coefficient of the dye-film at the infrared wavelength, with $a_y(p_{CO_2})$ independent of the film thickness. Combining equ. 6 with equ. 3, equation 7 can be got.

$$p_{CO_2} = [air[Ln(I_y/I_y0)/Ln(I_{ir}/I_{ir0})] - b_0]/b_1$$

(7)

where air, b₀ and b₁ are constants which are independent of film thickness. Therefore, the technique mentioned above can be used to measure p_{CO₂} with self-compensation for the film thickness.

3 Test results

Table 1 shows the sample data for three disks with different film thicknesses. The data of the three disks are different from each other. After compensation is made by using the software of equation 7, the displays of each disk are exactly the same.

Table 1 Compensation test results*

	Disk 1		Disk 2		Disk 3	
	0.03% CO ₂	3% CO ₂	0.03% CO ₂	3% CO ₂	0.03% CO ₂	3% CO ₂
Dark	193	193	193	193	193	193
Yellow	37	59	45	63	53	64
Infrared	128	128	135	136	130	132
Display	0.0	3.0	0.0	3.0	0.0	3.0

* The test was made in Biomedical Sensor's Unit, University of Swansea, U.K.

4 Conclusion

The test results have shown that the thickness compensation algorithm has satisfactorily compensated the thickness difference.

[References]

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双波长涂膜 CO₂ 传感器涂膜厚度补偿

俞光昀

(南京师范大学数学和计算机科学学院, 210042, 南京)

[摘要] 介绍了对双波长涂膜 CO₂ 传感器涂膜厚度差异的补偿算法, 该算法能够自动有效地补偿涂膜厚度差异对测量结果的影响.
[关键词] CO₂ 浓度测量, 双波长, 涂膜传感器, 厚度补偿

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