The Detection of Volatile Organic Compounds (VOCs) Emissions by Using Photoacoustic Method- A Case Study of Formaldehyde

Haw Farn Lan, Way Long and
Yaw Fuh Huang
Department of Wood Science
and Design

I. Introduction

Building materials such as wood based materials, adhesive, paints, varnish, and vinyl floorings are important sources of volatile organic compounds (VOCs). Taiwan is located in subtropical and tropical zone where the climate is typically hot and humid for the whole year. Therefore, they have been used widely as interior building material. However, there are several hundred different pollutants in ambient indoor environment. Formaldehyde is often considered as one of the most dangerous toxins that can be found in living space.

None of VOCs (such as formaldehyde) detected methods fulfilled the requirements for an ideal detection technique. The application of several different approaches in formaldehyde emission measurements gives reasonable amount of information to make conclusions concerning formaldehyde emissions and abatement possibilities[7]. The originality photoacoustic (PA) system employed was designed for simultaneous response, low electronic, and high sensitivity. In order to facilitate their identification without a molecule specific separation step preceding the PA measurement, and to reduce the interference of water absorption the IR characteristic region should be selected for the utility of this experiment design.

II. Experimental

Photoacoustic is a calorimetric method, in which the optical energy absorbed in a gaseous species is directly measured through the heating produced in the medium. The small local temperature variation in the gas is associated to a pressure variation. When the deposited optical energy is modulated, a periodic heating is produced, thus generating a modulation of the sample pressure. This results in an acoustic wave, which can be detected using a sensitive miniature microphone. Therefore, the PA effect can be divided into five steps (Figure 1):

The absorbed energy is converted into acoustic energy that is cause the atoms

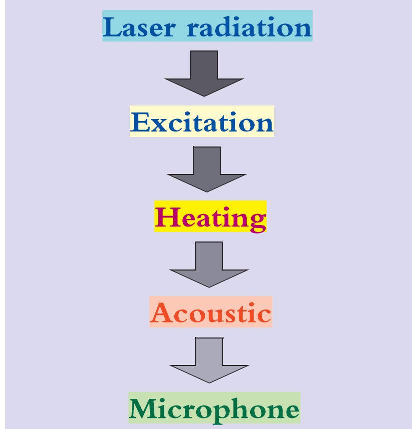


Figure 1. The photoacoustic basic theory

in the gas molecule to vibrate. Therefore, as the light is chopped, the heated gas expands and causes a pressure rise which will alternately increase or decrease the sound pressure levels. The magnitude of the sound pressure signal that results is described by the equation:

$$\text{Sound pressure level} \propto \frac{\left(\frac{C_p}{C_v}-1\right)\sigma m I_0}{\nu_a}$$

σ = a constant coefficient,
C_p 、 C_v =the heat capacity of the gas at constant pressure and constant volume,
m = the gas concentration,
I_o = the intensity of light,
ν_o = the light chopper frequency.

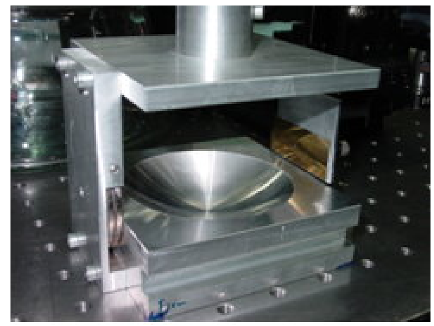
III. Materials and Methods

Photoacoustic systems

The photoacoustic system designed to compose of the equipments and procedures which can be divided into four units part shown in Figure 2: (1) Light source - the optical parametric oscillator laser (OPO) (2) Multipass acoustically open photoacoustic detector (MOPAD) (3) Desiccator chamber and (4) Lock-in amplifier analysis system.

Multi-pass acoustically open photoacoustic detector (MOPAD)

The MOPAD consists of two optical mirrors and acoustic reflectors. The two parallel gold coated optical mirrors reflected the laser beam with a designated path. A microphone sensor was located at the center of the plane carved out by the laser beam (Figure 3).



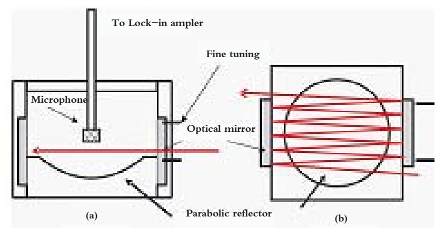


Figure 3. Schematic views of the MOPAD detector: (a) the plane of the drawing is normal to the plane of the optical mirrors and contains the acoustic axis; (b) View of MOPAD showing the path of the multiple passes of the laser beam inside the detector.

IV. Results

The photoacoustic spectra were taken by scanning the OPO (2796cm^{-1} ~ 2806cm^{-1}) through a wavelength range where formaldehyde absorbs (Figure 4). The moisture absorption lines could overlap most of the formaldehyde lines at 2801.5 cm^{-1} and 2082.9 cm^{-1}. However, PA methods could detect the amounts of formaldehyde and negligible water vapor effect in the ambient. A spectral feature of formaldehyde, centered at 2805 cm^{-1} and free of water-interference, was used to evaluate the sensitivity of our technique for detecting formaldehyde

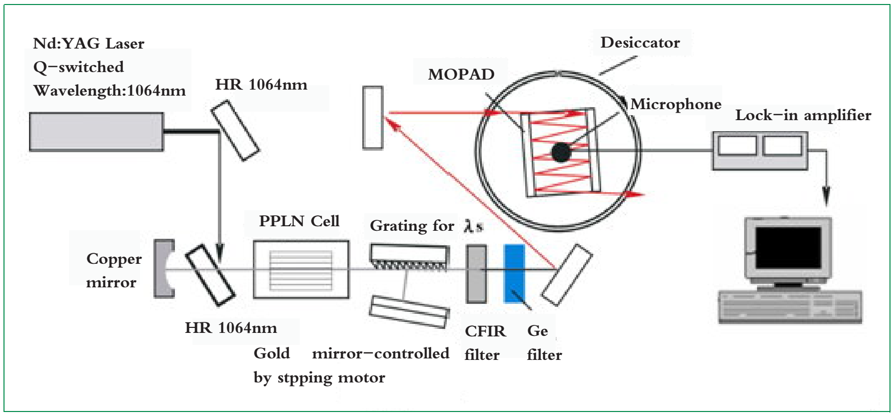


Figure 2. Schematic illustration of the OPO-MOPAD measurement setup with the desiccator test cell.

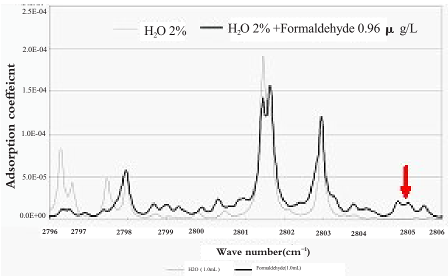
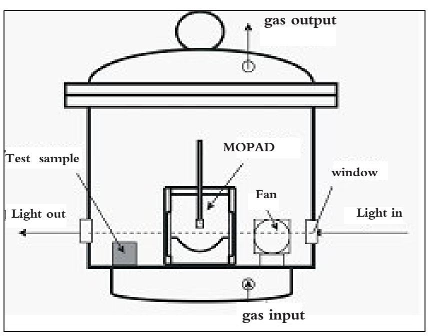


Figure 4. The comparison of spectra (2796cm-1 ~ 2806 cm-1) calculated for formaldehyde and moisture in ambient laboratory air.

Calibration of the equipment was performed at 2805 cm-1 using the modified standard formaldehyde (0.05~1.5mg/mL) that were tested to draw the calibration curve (Figure 5).



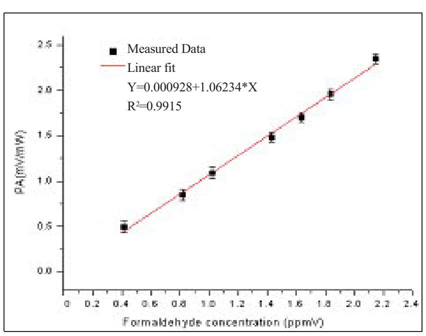
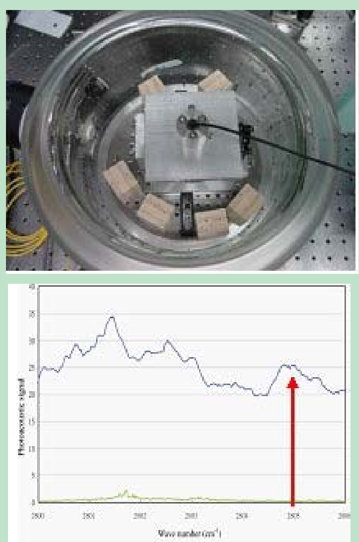
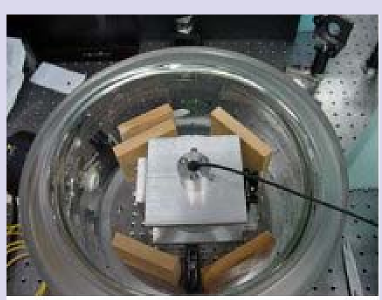


Figure 5. Potoacoustic methods calibration curve measured for formaldehyde between 0.05~1.5mg/mL.

Formaldehyde emission of the wood based composited materials

The initial and subsequent formaldehyde emissions from the products were determined by testing MDF and LVL at 22°C, RH 60% from formaldehyde collected in the desiccator chamber with analysis by photoacoustic method. the concentrations of formaldehyde in LVL (9.2 mg/L) and MDF (0.185 mg/L) were recorded by the photoacoustic method (Figure 6).





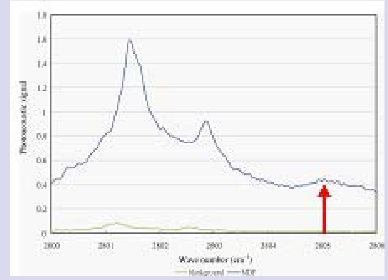


Figure 6. Measured photoacoustic spectrum of (a)LVL and (b)MDF formaldehyde emission in ambient laboratory air.

Formaldehyde adsorption of the bamboo charcoals

The bamboo charcoals were derived by the variation of activation temperature. Therefore the surface chemistry of charcoal affects the adsorption capacity significantly while the texture characteristics of surface area and pore volume play a minor role in formaldehyde adsorption. The results from Figure 7, the photoacoustic indicated that the adsorptive capacity of bamboo charcoal and initial 1.8 ppmV formaldehyde decreased to 0.2 ppmV.

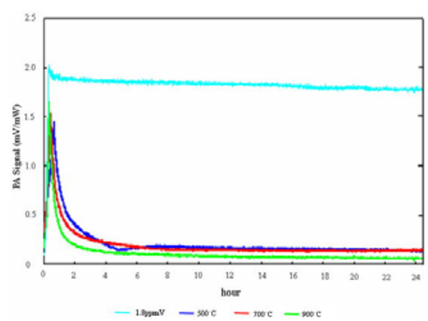


Figure 7. The formaldehyde adsorption history obtain the various charcoalization bamboo charcoals in the small chamber under ambient air.

V. Conclusions

The high sensitivity of photoacoustic detection and the ability to make measurements in real time allow the characterization of materials and the monitoring of trace gases in a realistic environment. It is an effective method for evaluating the reduction performance of adsorption charcoal and the quantitatively evaluation can be measured simultaneity. This study was successful in designing a highly sensitivity and excellent selectivity method in detecting formaldehyde emission from

MDF and LVL were accomplished. Furthermore, we demonstrated its sensitivity with trace detection of formaldehyde and the use of the apparatus for time-resolved measurement of the gas adsorption in bamboo charcoal.

In future research, the photoacoustic system will be improved to solve more complex problems, such as monitoring the indoor air quality associated with VOCs.

VI. Acknowledgements

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