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PRACTICAL APPLICATIONS OF PHOTOACOUSTIC SPECTROSCOPY

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INTRODUCTION

Initial work on photoacoustic spectroscopy has concerned the measurement technique itself. The transition to the practical application of photoacoustic spectroscopy in solving real problems has been slow. This development is illustrated in an analysis of the published literature from 1973 to and including 1979 (figure 1). A patent application for a photoacoustic spectroscopy was filed by Rosencwaig in the middle of 1973. For about two years Rosencwaig was nearly alone in presenting various aspects of photoacoustic spectroscopy in informational (popular and popular-scientific) articles. Several articles on the theory on photoacoustic spectroscopy followed, and there is continued activity on the theoretical aspects. About three years after Rosencwaig's patent application articles concerning experimental aspects of the photoacoustic method began to appear, followed by reports in which photoacoustic spectroscopy was used to solve practical problems. It is these applications of photoacoustic spectroscopy which must grow and develop in order that photoacoustic spectroscopy as a method be successful.

BINDER CONTENT OF MINERAL WOOL

We have applied photoacoustic spectroscopy to several industrial problems. One project was to measure the binder content of mineral wool for thermal insulation, and we studied both Rockwool and Gullfiber products, with interesting results.

A photoacoustic apparatus for quality control can be simpler than a research instrument. The monochromator was replaced by interference filters with relatively wide bandwidths. We used filters in the blue and red parts of the visible spectrum since we knew that the binder absorbs light in the blue and the fibers absorb in the red. Further, the variable frequency chopper was eliminated in favor of a filament light which was modulated at double the line frequency, 100 Hz. The phase locked amplifier was replaced by a very narrow band active filter with peak at 100 Hz. Finally, a large diameter (10 cm) sample cell which could be loaded in the apparatus quickly allowed relatively large sample volumes to be investigated.

In order to measure the binder content of Rockwool we measured the ratio of the signal strengths for the blue and red filters, thus using a normalization procedure to avoid several instrumental standardization and calibration problems.

In the experiments we measured the ratio of the two signal strengths as a function of the known binder content for a large number of samples. Some of the results are shown in figure 2 a. There is a positive correlation between the binder content and the signal ratio, which is the expected result.

Our study of Gullfiber insulation material proceeded along similar lines. The binder in Gullfiber absorbs strongly in the blue region of the visible spectrum and the fibers themselves absorb very little over the whole of the visible spectrum. Therefore a positive correlation of the signal ratio was expected. The results of the measurements are shown in figure 2 b.

Figure 2 b shows an unexpected result: the correlation between the signal ratio and the binder content is negative. This is because the binder content of Gullfiber is much higher than that of Rockwool and saturation effects play a decisive role in the blue part of the spectrum. When the binder content is increased the amount of blue light absorbed is unchanged since the binder already looks "black". However, the amount of light absorbed in the red region increases because of the light absorption of the binder in the red region of the spectrum. Since this increase is stronger in the red than in the blue, a decrease in the signal ratio is obtained.

PROTEIN CONTENT OF FLOUR

In another application we measured the protein content of flours. It is also important to control the water content of flour as this can influence the storage properties. Most proteins have a rather non-specific absorption in the near ultraviolet, with peak absorption around 2 700 Å. We measured the photoacoustic spectra of twenty different flour samples over the near ultraviolet and visible regions of the spectrum and correlated the signal strengths with protein content by studying the results at 2 700 Å and other wavelengths as a function of the known protein content.

Several questions relating to experimental procedure are immediately apparent. One concerns the effect of packing the flour in the sample cell. This was tested by measuring several samples with varying packing and sample amount with the result that these variations did not influence the measurement results. However, it was found that the signal amplitudes varied in time as the samples were studied. This change was constant over the entire spectral range, that is, the shapes of the spectra did not change. As it was suspected that the water content of the samples changed, some of the samples were dried in an oven. After drying, the signal strengths increased by almost a factor of seven. Thus the water content of the flour, normally around 10 %, has a strong influence on the signal strength.

Having gained control of these factors the protein content was further investigated. The signal strength at 2700 Å correlated well with the protein content of the flour for low protein contents (under 15 %) as well as did the ratio of the signal strengths at 2700 Å and 4500 Å. However, the correlation was poor at intermediate protein contents. At high protein contents (above 20 %) the signal strength at 2700 Å increased relatively little with increasing protein content, while the ratio of the two signal strengths decreased somewhat. Some illustrative results are shown in figure 3. This is recognized as the saturation effect which was noted in the work on Gullfiber.

LIGHT SCATTERING

Measurements on opaque or light scattering liquids are difficult with conventional spectroscopic instruments. Photoacoustic spectroscopy is well suited to such measurements, especially since the role of light scattering has how been clarified (Per Helander, Ingemar Lundström and Douglas McQueen, J Appl Phys 51, 3841 (1980)). However, continuous on-line or flow-through measurements have not been possible until recently, because of the requirements of a closed sample volume in conventional photoacoustic sample cells (an exception is A C Tam and C K N Patel, Optics Letters 5, 27 (1980)).

Clarification of the role of light scattering and the development of flow-through cells make on-line measurements on liquids such as milk and blood practical. Previous work on the protein and fat contents of milk and milk products (Per Helander, unpublished work) can be properly calibrated when light scattering is taken into account. Use of flow-through cells in this connection would lead to new, faster and less expensive measurements of the protein and fat contents of dairy products.

FLOW-THROUGH CELL

We discuss the design and application of a photoacoustic sample cell (figure 4) for flow-through measurements briefly. The flow-through cell should be of interest in medical and process applications because of its simple and robust design. Further, since it is a flow-through cell larger volumes of sample liquids can be interrogated spectroscopically than is the case with conventional sample cells. This may open up new applications for photoacoustic spectroscopy to practical use as a process control method.

Figure 1. Numbers of various types of publication about photoacoustic spectroscopy, per year.

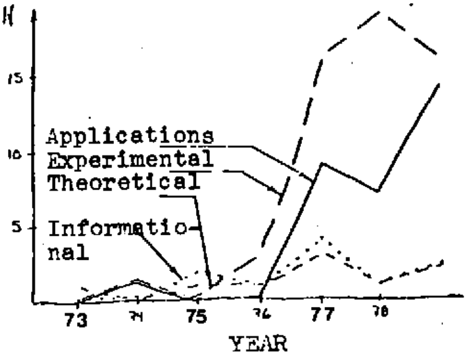

Figure 2. Signal ratio vs binder content of mineral wool:
a) Rockwool
b) Gullfiber

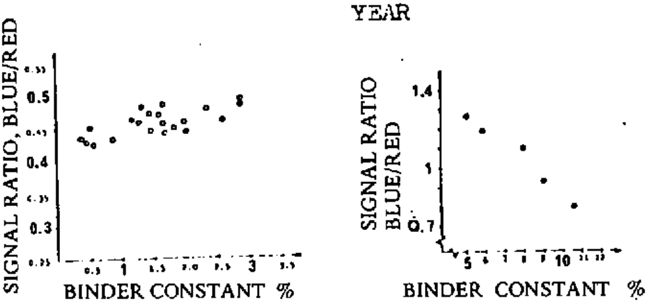

Figure 3. Two spectra for flours with different protein contents.

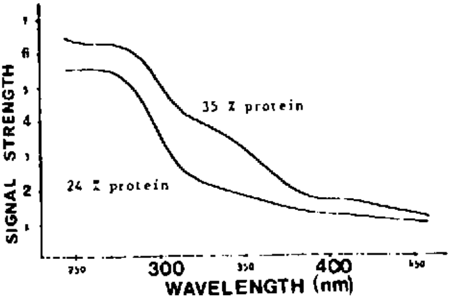

Figure 4. A new type of flow-through photoacoustic cell.