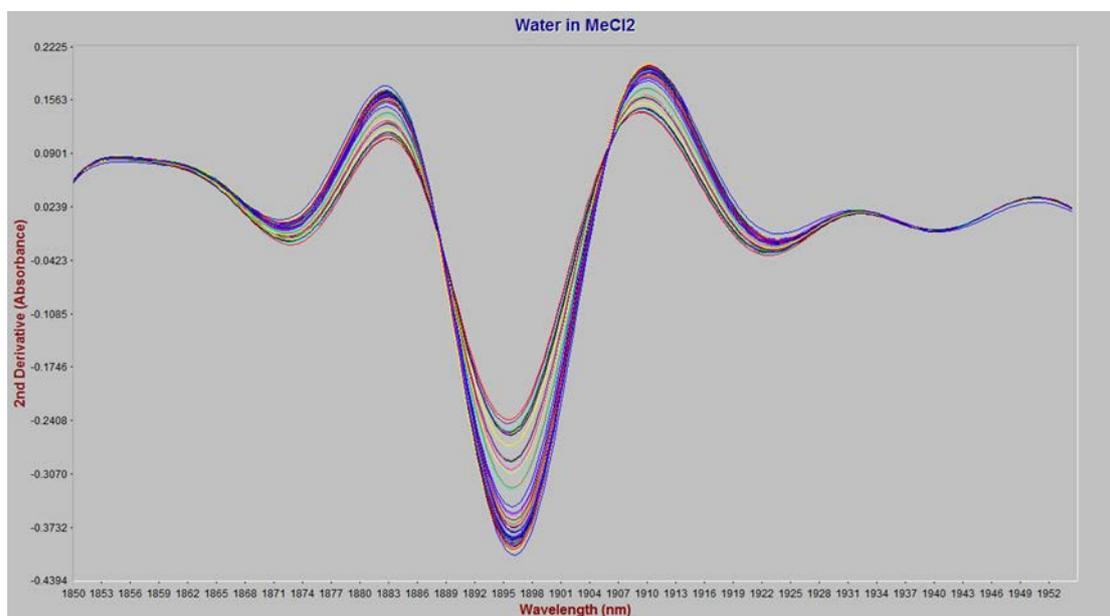


Monitoring the purity of recovered solvents by NIRS



The purity of a solvent (dichloromethane/methylene chloride) is monitored by NIR spectroscopy along with two of the major impurities (methanol and water).

Method description

Introduction

The solvents that are used in manufacturing processes are often not disposed of or incinerated, but instead recovered and purified, as this saves considerable costs. Used solvents are mostly purified by distillation. Solvent recovery processes are very common in the chemical industry and in the pharmaceutical industry in the manufacture of APIs (Active Pharmaceutical Ingredients).

Near-Infrared (NIR) spectroscopy can be used to ensure that the solvents are sufficiently pure for reuse in manufacturing. It requires no sample preparation and produces results in a matter of seconds. Furthermore, it does not require trained analysts, and it can be performed as a lab method using grab samples or directly inline.

Experimental

Samples of methylene chloride (MeCl_2) solvent were taken from the output of a solvent recovery distillation unit. The samples covered the range of typical levels of purity and levels of methanol and water impurities in the distilled solvent.

No sample preparation was required. Samples were scanned directly in their sample collection jars using a NIRS XDS SmartProbe Analyzer (Figure 1), which uses a fiber optic immersion probe to direct the NIR energy to the sample. With this probe design, the NIR energy from the spectrometer passes through the solvent, hits a reflector, and then passes back through the solvent to the detectors. The gap between the probe and reflector is 2 mm, which makes the actual spectral path length 4 mm. 16 scans of the sample were co-added and subsequently ratioed to 16 co-added scans from the probe in air as a reference.

The NIRS XDS SmartProbe Analyzer scans the entire NIR range as well as the visible spectrum, providing a scan from 400 to 2500 nm in less than 30 s (including reference and sample scans). Fiber optics absorb above 2200 nm, so the region from 2200–2500 nm will not be used in any of the calibrations.



Figure 1: NIRS XDS SmartProbe Analyzer

The samples were analyzed by GC (organic impurities) and Karl Fischer titration (water) immediately after scanning to avoid any changes in the samples over time. The sample temperature was not controlled, and varied with the ambient conditions in the laboratory for all of the NIR measurements.

Results

The absorbance ($\text{Log } 1/T$) spectra of the recovered solvent samples are shown in Figure 2.

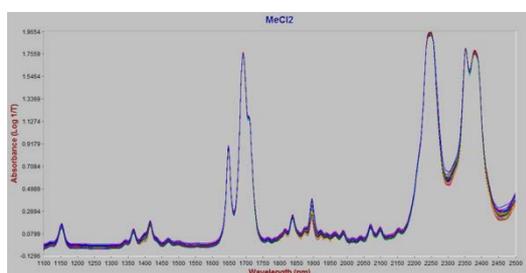


Figure 2: Raw absorbance spectra of methylene chloride calibration samples

Because of the choice of 4 mm path length, the band near 1700 nm is in a non-linear absorbance range, and was not used in any of the calibration equations. As noted earlier, the fiber optics absorb significantly in the region above 2200 nm; this region was not used in any calibration equations, either. The remainder of the spectrum is in a linear absorbance range. It includes regions where both the solvent and the impurities have absorption bands.

The 2nd derivatives of the absorbance spectra were calculated. They are shown in Figure 3.

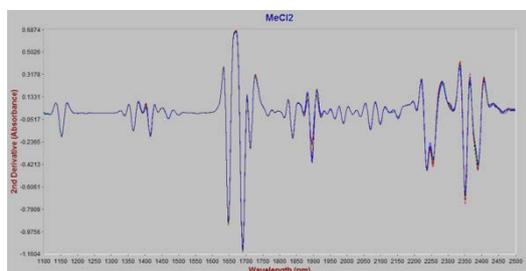


Figure 3: 2nd derivative spectra of methylene chloride calibration samples

Method description

This math pretreatment was performed to enhance spectral features and to eliminate any baseline variations. The variations in band intensity (e.g., of the moisture band near 1900 nm) are more pronounced in the 2nd derivative spectra than in the raw absorbance spectra. **Figure 4** shows the region near the 1900 nm water band. The intensity differences for samples containing different levels of moisture are clearly visible.

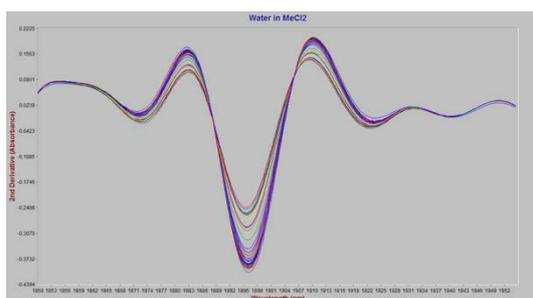


Figure 4: Moisture band (2nd derivative) for calibration samples

The 2nd derivative spectra and the corresponding Karl Fischer data were used to develop a Partial Least Squares (PLS) calibration model for the prediction of moisture. Only the spectral region from 1800–2000 nm around the water absorbance band was used. The PLS calibration used only 3 PLS factors; the results are shown in **Figure 5**.

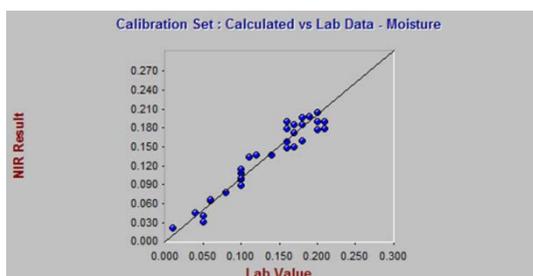


Figure 5: Calibration results for moisture in methylene chloride

The standard error of calibration (SEC) was 0.0156%. This is comparable to the accuracy of Karl Fischer water determination at these concentration levels. A second set of data was used as a validation set. The standard error of prediction (SEP) was 0.0133%, about the same as the SEC, indicating that the calibration is not overfit and will be as accurate as the Karl Fischer determination for future samples.

In addition to water, methanol was present in the solvent as an impurity. **Figure 6** shows the 2nd derivative NIR spectra for the samples in the region near the O-H combination band region for alcohols.

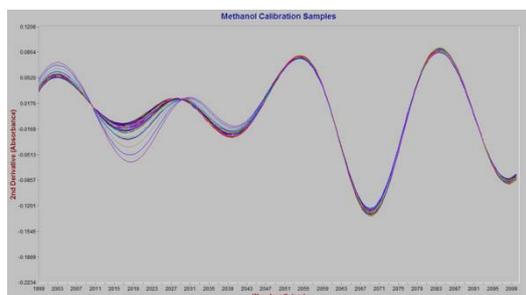


Figure 6: Methanol calibration sample spectra – calibration wavelength range 2000 – 2100 nm

There is an evident intensity variation near 2020 nm between the spectra of samples containing different methanol levels. A PLS calibration model was developed using the 2000–2100 nm region of the 2nd derivative spectra and the GC results for these samples. The results are shown in **Figure 7**.

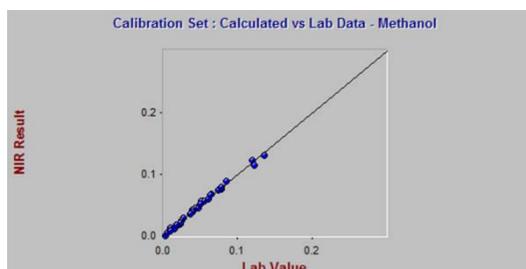


Figure 7: Calibration results for methanol in methylene chloride

The calibration error (SEC) was 0.0031%, which is similar to the accuracy of methanol determination by GC. This calibration was used to predict the methanol content in a validation set of samples. The SEP (0.0034%) is about the same as the calibration error, indicating that this model should predict the methanol content of future samples accurately.

The overall solvent purity was also modelled by PLS. There were several other impurities besides moisture and methanol in these samples, and all usable spectral regions (1120–1680 nm, 1720–2200 nm) were used to model the solvent bands as well as the bands of all impurities. The reference values were calculated from the GC results as 100% methanol minus the contributions of all impurities appearing in the chromatogram. **Figure 8** shows the calibration results.

Method description

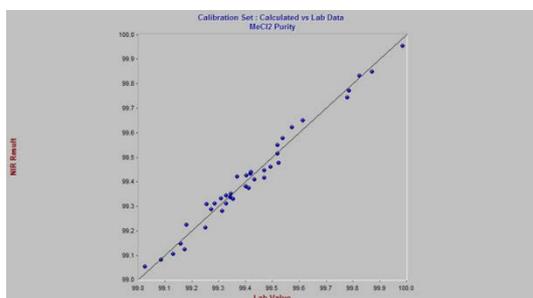


Figure 8: Calibration results for purity of MeCl₂

The range of purity was 99–100%, and the SEC for the calibration was at 0.043%. A second set of samples was scanned and used as a validation set. The SEP (0.0455%) was very similar to the SEC, indicating a good predictive accuracy, similar to the accuracy of the GC determination of overall purity.

Conclusion

NIR spectroscopy can be used to analyze the concentration of several impurities in recovered solvents and estimate their overall purity. Multiple analyses can be done simultaneously in less than 30 seconds total analysis time. While this study was done using a NIRS XDS SmartProbe Analyzer in a laboratory environment, the application could also be done with a NIRS XDS Rapid Liquid Analyzer – using cuvettes or disposable vials. Alternatively, these analyses can be done directly in the distillation process (liquid output stream of the distillation column) with a fiber-optic-based NIRS XDS Process Analyzer. In the latter case, the entire distillation process can be monitored and controlled by the NIR analyzer.