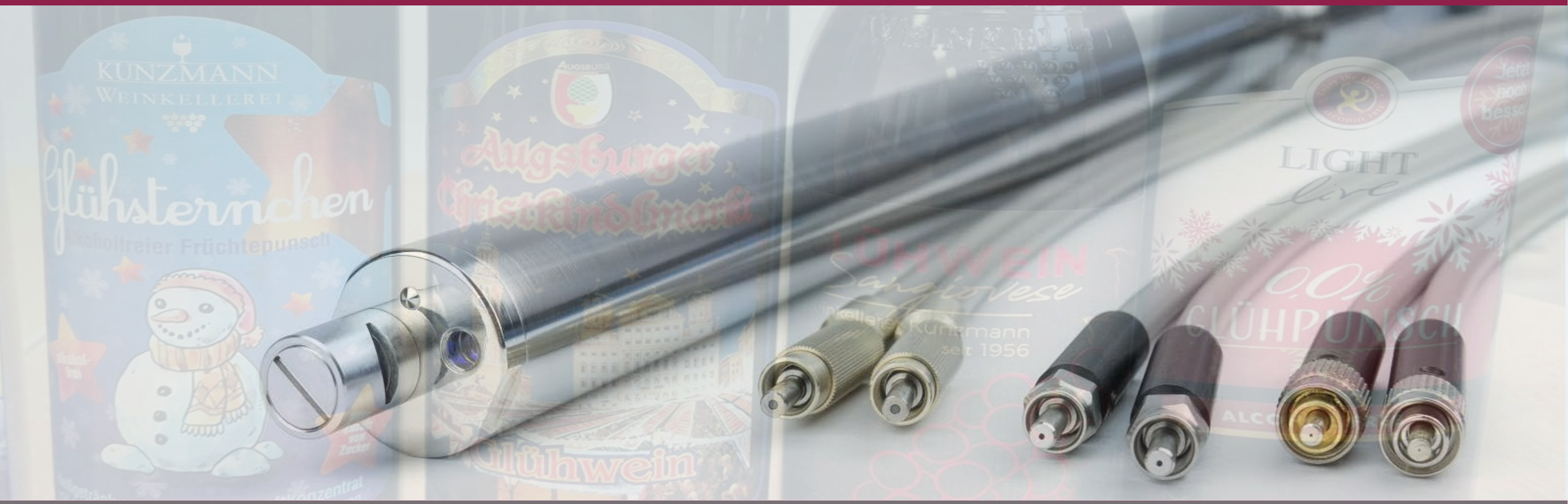

Monitoring Ethanol Evaporation in Mulled Wine using Fiber-Based MIR Spectroscopy

This application note highlights the use of fiber-based MIR spectroscopy to monitor temperature-induced chemical changes in liquids with an example of monitoring of ethanol evaporation in mulled wine during heating.

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Introduction

During Christmas time, a walk on Christmas markets is a tradition that many people do not want to miss. Even though the snow is mostly missing, a hot cup of mulled wine is mandatory for a nice walk over Christmas markets. One question that often arises is: why does mulled wine have its particular serving temperature?

According to gastronomy rule, the optimal drinking temperature for mulled wine is between 72°C and 73°C, as the aromas develop particularly well at this temperature. On the other hand, this temperature is just below the boiling point of ethanol (~78°C), preventing significant alcohol evaporation.

To investigate the spectral behavior of ethanol in mulled wine as it is heated, a mid-infrared (MIR) spectroscopy was employed. The setup includes a diamond ATR fiber optic probe, the Bruker Alpha spectrometer with an inserted Fiber Coupler (**Figure 1**). Measurements were taken using 64 scans at a resolution of 2 cm^{-1}.

Figure 1. Exemplary Laboratory Setup with Bruker Alpha spectrometer with inserted Fiber Coupler and Diamond ATR Fiber Probe.

In the initial experiment (**Figure 2**), mulled wine was gradually heated from room temperature up to 80°C in 5°C increments. The corresponding spectra were overlaid for comparison. Despite reaching high temperatures, ethanol remained present due to the short heating duration and minimal evaporation - helped in part by the small opening of the container. For reference, a scaled ethanol spectrum was added to the plot.

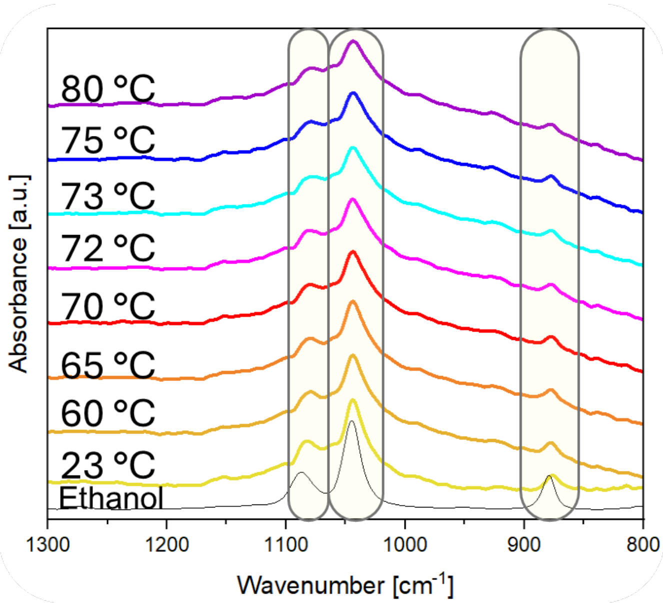

Figure 2. Temperature-dependent MIR spectra of mulled wine recorded using a Diamond ATR Fiber Probe connected to a Bruker Alpha spectrometer via the inserted fiber coupler. Characteristic ethanol peaks are observed at 1084 cm^{-1}, 1043 cm^{-1} and 876 cm^{-1}.

In a second experiment, the mulled wine was heated to 90°C and maintained at this temperature for approximately two hours, ensuring complete ethanol evaporation. This process was continuously monitored using the fiber-optic probe, demonstrating the capability to observe real-time chemical changes induced by heat. Such measurements are not limited to ethanol but are broadly applicable to any process where temperature variations lead to spectral changes.

Figure 3 illustrates both the start and end points of this evaporation process. Initially, spectra were recorded at 30°C, 40°C, and 60°C, clearly showing ethanol's presence. After 2 hours heating at 90°C, the resulting spectrum resembled that of grape juice, where ethanol is absent and different kinds of sugars dominate the MIR region. These sugar compositions can be further analyzed and differentiated using Principal Component Analysis (PCA) or spectral deconvolution techniques.

This example demonstrates the possibility of using fiber-coupled MIR spectroscopy in monitoring thermally induced chemical changes. The approach is ideal for direct in situ analysis in applications where heat is a factor - ranging from food and beverage to pharmaceuticals and environmental monitoring.

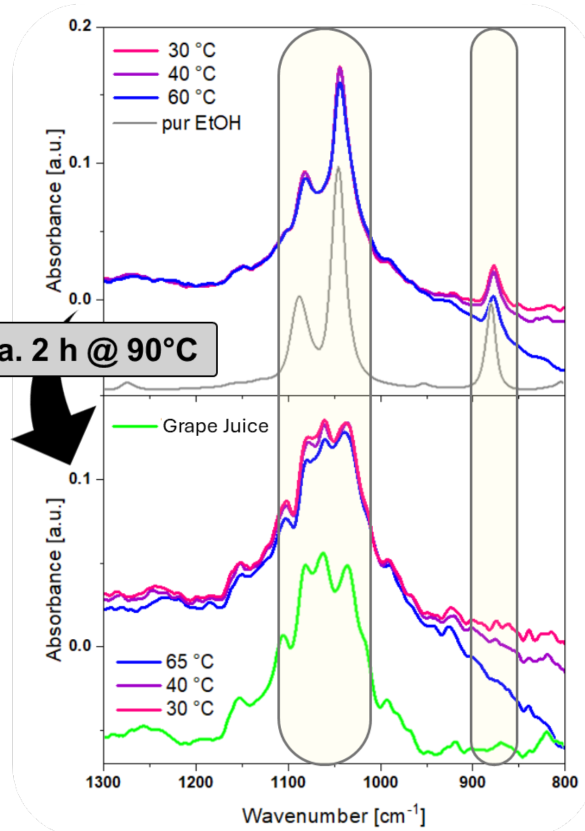

Figure 3. MIR spectra of mulled wine before and after extended heating. Following prolonged heating ("cooking") at 90 °C, the spectral profile indicates that ethanol has been fully evaporated and shows spectral features of grape juice due to sugar compounds.

Conclusion

The evaporation of ethanol from mulled wine can be monitored using fiber-based MIR spectroscopy. This technique offers real-time, non-destructive insight into chemical transformations driven by temperature. When combined with other fiber-optic probes, even more comprehensive spectral information can be obtained, making this a powerful tool for a wide range of analytical applications.

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