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Beyond the Ion Source: Optimizing GC/MS Sensitivity with Capillary Chromatography

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Introduction

Evolutions of ionization sources have allowed to push the limits of detection in gas chromatography/mass spectrometry (GC/MS) down to attogram levels with the Agilent 7010D triple quadrupole GC/MS system. At such low concentrations, impacts due to matrix, column phase selection, and thermal stability will have greater impact on peak shape and can have the potential to limit sensitivity. Additionally, interactions between solvent polarity and column phase polarity will also impact solvent focusing and may lead to the distortion of peaks. In the analysis of trace-level analytes, splitless and pulse splitless injections are needed to achieve the desired sensitivity, but this will also increase the solvent introduced to the head of the gas chromatography column and the possibility of interactions between the solvent and the analytical column phase.[1]

In this poster we will examine how interactions between traditional and nontraditional solvents and column phase used in gas chromatography impact sensitivity, illustrate the mechanism of action, and discuss strategies to mitigate risk and maintain sensitivity for trace level analytes.

Experimental

An Agilent 8890 GC coupled with an Agilent 7010D HES 2.0 was used for data acquisition and Agilent MassHunter Qualitative Analysis software, version 10.0, was used for data analysis. A representative pesticide mixture, Agilent Pesticide checkout solution (p/n 5190-0468), was prepared in acetonitrile and dichloromethane at concentrations ranging from 10 to 500 ppb to monitor analyte response from interactions between column phase and solvent polarity.

Agilent 8890 GC	
Inlet	300 °C, pulsed splitless, 50 psi until 0.75 min
Purge Flow to Split Vent	50 mL/min at 0.7 min
Injection Volume	1.0 mL
Inlet Liner	Ultra Inert, split, low pressure drop (p/n 5190-2295)
Gas Saver	On, 20 mL/min after 3 min
Septum Purge Flow	3 mL/min
Oven	80 °C (1.5 min), ramp 40 °C/min to 120 °C, ramp 5 °C/min to 310 °C (10 min)
Column	
Carrier Gas	Helium, 1.37 mL/min, constant flow
Column	Agilent J&W DB-5Q 30m x 0.25 mm x 0.25 µm (p/n 122-5532Q) Deactivated fused silica, 1 m, 0.25 mm id (p/n 160-2255-1)
Inlet Connection	Split/splitless inlet
Outlet Connection	MSD

Solvent Focusing and Cold Trapping

Proper solvent focusing

During the reconcentration process, liquid will form a thin film on the head of the column, called the flooded zone. The reconcentrated solvent helps to trap analytes in this zone and prevents them from moving through the analytical column by forming a barrier, as seen in Figure 1, also known as a retention hill. When the flooded zone is optimally concentrated, this would be deemed as being optimally focused. In general terms, the greater the reconcentration, the greater potential for sharper analyte bands.

As the condensed solvent evaporates, the portion closest to the hot inlet will evaporate first. The recondensed solvent will be replaced by solvent vapor and the thin layer of solvent phase will evaporate, leaving the solute condensed on the column head, as seen in Figure 1. The rate of solvent evaporation depends on the volatility of the solvent and the volume of solvent present. If analytes have a similar volatility to the solvent or a greater affinity to the solvent, this can lead to peak distortion.[1-3]

Cold trapping

After the solvent and analytes create the short-lived film at the head of the column, the solvent evaporates, leaving the analytes at the head of the column. This can only occur once the oven temperature is greater than the boiling point of the solvent. As many gas chromatography methods begin with an oven temperature of 40 °C or greater, a solvent such as dichloromethane that has a boiling point of 39.6 °C proves to be an optimum solvent for evaporation and leaving analytes at the head of the analytical column.

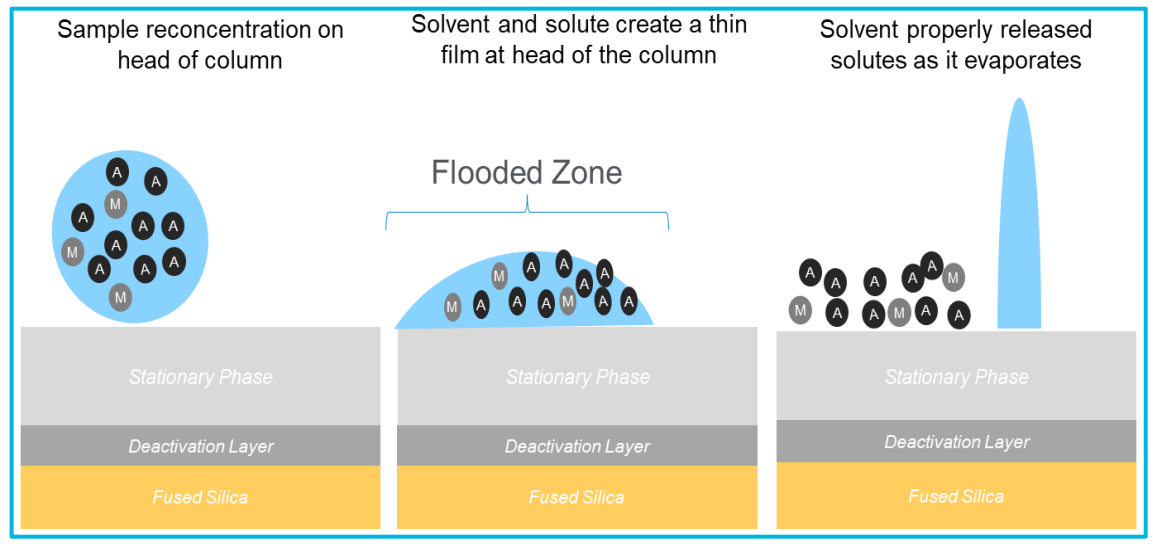

Figure 1. Example of how a sample reconcentrates on the head of the gas chromatography column and spreads to form a thin film. The solvent then evaporates, leaving analytes at the head of the gas chromatography column.

Solvent Polarity and Column Phase Polarity Interactions

To determine which solvents should be used with which column phases, and which solvents should be avoided, a general rule is to match the polarities of the column phase with the polarity of the solvent, shown in Table 1. For example, if a column with low polarity, like an Agilent J&W DB-5 is used, it would be recommended to use a solvent that also has low polarity, such as hexane. Occasionally, it can be possible to use a nonpolar column with a midpolar solvent, such as using dichloromethane with a J&W DB-5 type column, but it is not recommended to use a polar solvent, such as acetone or acetonitrile.[4]

Prior to efficient sample preparation methods for pesticide analysis, a guard column has been used to help protect the analytical column from heavy matrix or nonvolatile analytes. The primary method of sample preparation used was solvent dilution in hexane or dichloromethane, potentially passed through a filter, and then injected directly into the inlet and analyzed on a 5% phenyl phase type column. As dichloromethane and hexane are both compatible solvents with a 5% phenyl phase, the guard column was only needed to protect the analytical column from matrix, and not from adverse wettability.

With the adoption of more involved sample preparation techniques traditionally used in liquid chromatography, samples typically finish their preparation in the polar solvent acetonitrile.

While this solvent is optimal for use with liquid chromatography, there could be adverse interactions when used for gas chromatography, especially when used on a nonpolar gas chromatography column phase.[8]

Solvent	Polarity Index	Phase Polarity	Sample Phase Types
Hexane	0.1	Low	Agilent J&W DB-1, Agilent J&W DB-5
Carbon Tetrachloride	1.6		
Toluene	2.4		
Tert-butyl methyl ether	2.4		
Chloroform	2.7	Middle	Agilent J&W DB-35, Agilent J&W DB-17
Dichloromethane	3.1		
Isopropanol	3.9		
Tetrahydrofuran	4.0		
Ethyl acetate	4.4		
Acetone	5.1	High	Agilent J&W DB-624, Agilent J&W DB-Wax
Methanol	5.1		
Acetonitrile	5.8		
Water	9.0		

Table 1. Polarity index of various solvents used in gas chromatography and column phase general compatibility.

Peak Distortion Due to Improper Solvent Focusing

In addition to the recondensation and solvent focusing, there will be interactions with the column phase that can lead to proper or improper wettability. If the polarity of the solvent and the polarity of the column phase are not properly matched, this can lead to an increase in the size of the flood zone, as demonstrated in Figure 2, as the sample will bead up similarly to water on a freshly waxed surface.[2] The solutes will then recondense unevenly. As the size of the flooded zone is increased, the retention hill will be decreased, allowing some solutes to escape the solvent, leading to split peaks and increasing peak widths.[4] This can be referred to as a reverse solvent effect. As the analytes are spread out along a larger flood zone, there is also potential for increasing the number of interactions between the solvent phase and the column phase. If the analyte has a greater affinity for the solvent than the column phase, it can get partially trapped in the solvent and decrease the retention on the head of the column, causing a decrease in analyte response.

As acetonitrile is a more polar solvent, and the analysis of pesticides is performed on a nonpolar 5% phenyl column phase,[6] this creates a potential for improper wettability, affects peak shape, and causes a decrease in response that is seen in Figure 3.

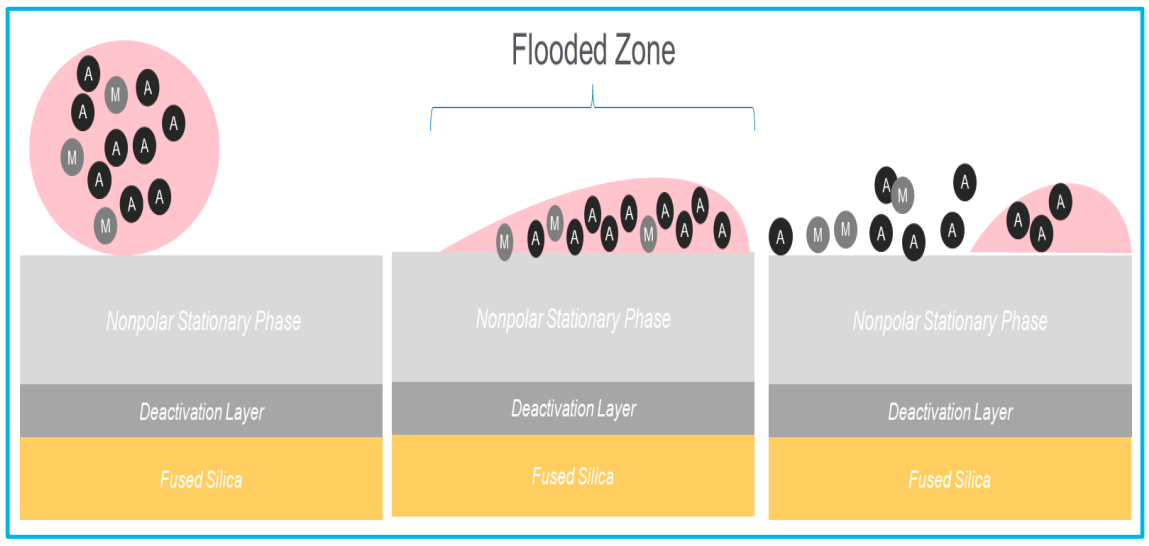

Figure 2. Example of how the flooded zone increases and solvent evaporation can be affected by solvent polarity and column phase polarity mismatch.

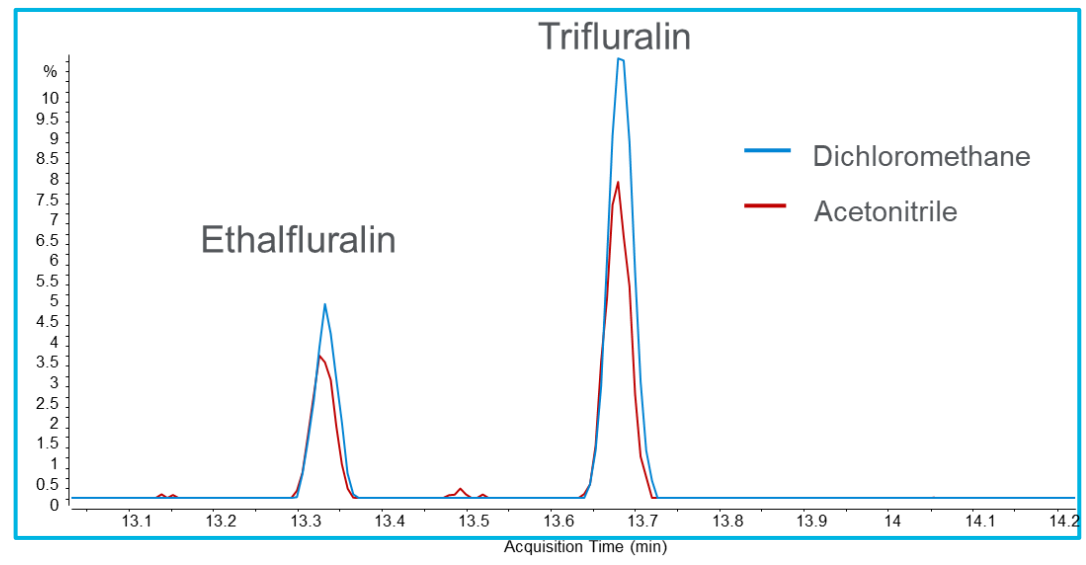

Figure 3. Example of a sample of pesticides prepared at 20 ppb and analyzed on an Agilent J&W DB-5ms Ultra Inert column prepared in dichloromethane and acetonitrile.

The Role of Thermal Stability and Solvent Focusing

A factor for determining the thermal stability of a GC column is due in part to the deactivation process of the fused silica and the natural presence of silanols on the surface of the fused silica. Depending on how the fused silica is produced, there can be differences in the concentration of silanols present, fully hydrated silica, and can range from 6 to 10 silanols per square nanometer on the capillary surface.

As analytes and solvent diffuse into and out of the analytical column phase, they will also interact with free silanols, and can lead to activity, which is why it is important to perform a silanol deactivation. This deactivation will decrease the silanol content as much as possible and can be done in a variety of ways.[7]

Polar solvents will have a greater affinity for silanols, and when the solvent is recondensed at the head of the column, the interaction between the solvent and silanols can cause a decreased flooded zone. Conversely, when less free silanols are present, the solvent has less affinity for the column phase and will cause an increase in the flooded zone.

With recent advancements in deactivation technologies, it has been possible to create a deactivation that further decreases the silanol content on the fused silica surface, creating ultrathermally stable and ultra inert columns. But as their silanol content is further decreased, mismatch in solvent polarity and column phase can lead to an increase of the flooded zone, especially in the case of splitless injections where the initial starting oven temperature is lower than the boiling point of the solvent.

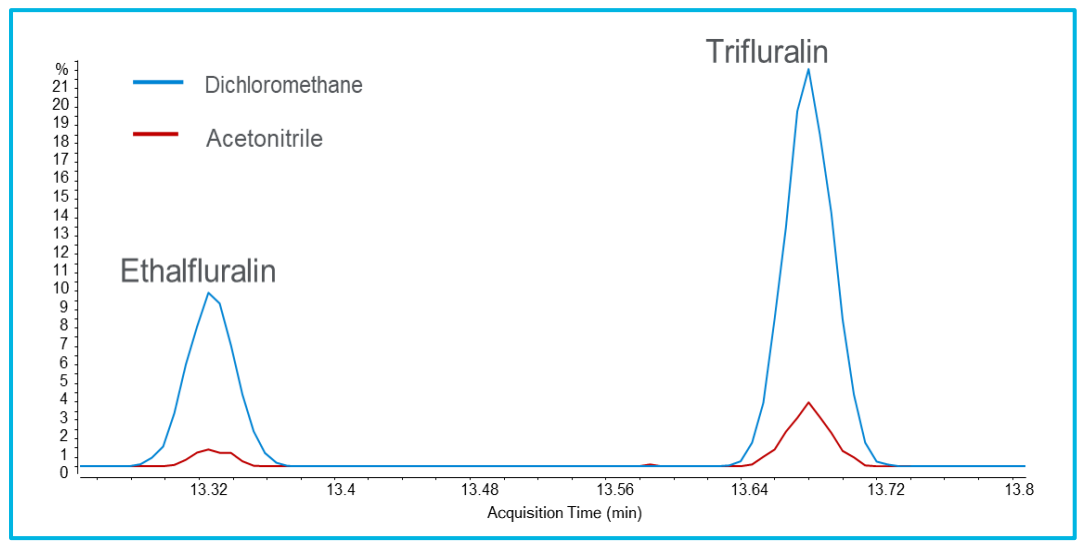

Figure 4. Example of a sample of pesticides prepared at 20 ppb and analyzed on an ultra low bleed GC column with decreased silanol content.

Refocusing with a Guard Column

Analyzing trace-level analytes that have been prepared in a polar solvent to be analyzed on a nonpolar column phase with further decreased free silanols on the surface of the fused silica can exacerbate the already prevalent issue of column phase and solvent mismatch. The use of a guard column can be used to decrease the flooded zone and refocus analytes, improve peak shape, and maintain sensitivity.[5] By adding one meter of uncoated and deactivated fused silica before the analytical column, it is possible to refocus the analytes, even when prepared in an improper solvent. The peak shape can also be improved, as is demonstrated in Figure 5, mitigating the risk of loss of sensitivity due to peak distortion.

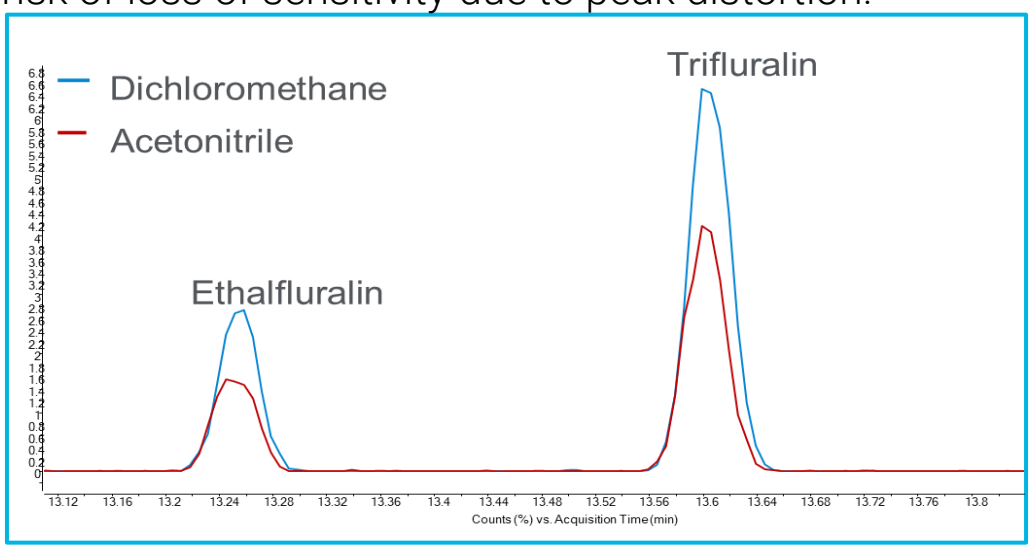

Figure 5. A sample of pesticides prepared at 20 ppb and analyzed on an Agilent J&W DB-5Q prepared in dichloromethane and acetonitrile with a one-meter guard column with an identical internal diameter as the analytical column.

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Conclusion

For a gas chromatography analysis to be successful there are many factors to consider, such as injection speed, solvent choice, installation of the column, and column phase selection. Solvent selection is important in more decisions than determining which solvent will dissolve analytes. Splitless injections will be more impacted by solvent selection, as there will be a greater amount of solvent introduced to the column and greater interactions between the solvent and column phase. To mitigate the problem of using a polar solvent with a nonpolar column, a guard column can be used to help refocus the solvent and analytes at the head of the analytical column and improve analyte peak shape.

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