Thermal Desorption Technical Support

Note 83: Enhancing TD-GC/MS methods for trace compound analysis using ClearView™ reprocessing software

Keywords:

Reprocessing software, GC/MS, Eliminate background interference, Trace analysis

Background

Thermal desorption (TD) is widely applied to the GC/MS measurement of trace toxic and odorous components in complex real world samples. It provides a versatile, robust, quantitative and automated alternative to conventional sample preparation methods (solvent extraction, *etc.*) and is now widely used to measure volatile and semi-volatile organic impurities in air/gas samples, manufactured goods, raw materials, natural products and a huge range of liquids, solids, pastes, emulsions, *etc.*

The technology works by thermally extracting/desorbing and refocusing vapour-phase organics in a single or multi-stage process (Figure 1). The last stages involve selective focusing of target analytes, typically using a small, electrically-cooled sorbent trap, which is subsequently desorbed by heating it rapidly (rates up to 100°C/sec) in a reverse flow of carrier gas. This injects/transfers the analytes into the GC/MS analytical system as a narrow band giving sharp capillary-compatible peaks. Significant concentration factors can be achieved (typically 10^3 to 10^6) while interferents such as air and water are purged to vent.

Since its introduction nearly 20 years ago, use of TD-GCMS has become increasingly widespread and it is now well documented in standard environmental methods[1-7] and in the scientific press[8-11]. Key fields of use include:

- Air (gas) monitoring – indoor air, ambient air, occupational hygiene, odorous emissions, process gases, *etc.*
- Counter terrorism – mobile first response, Depot Area Air Monitoring systems (DAAMS) and continuous monitoring of strategic public buildings

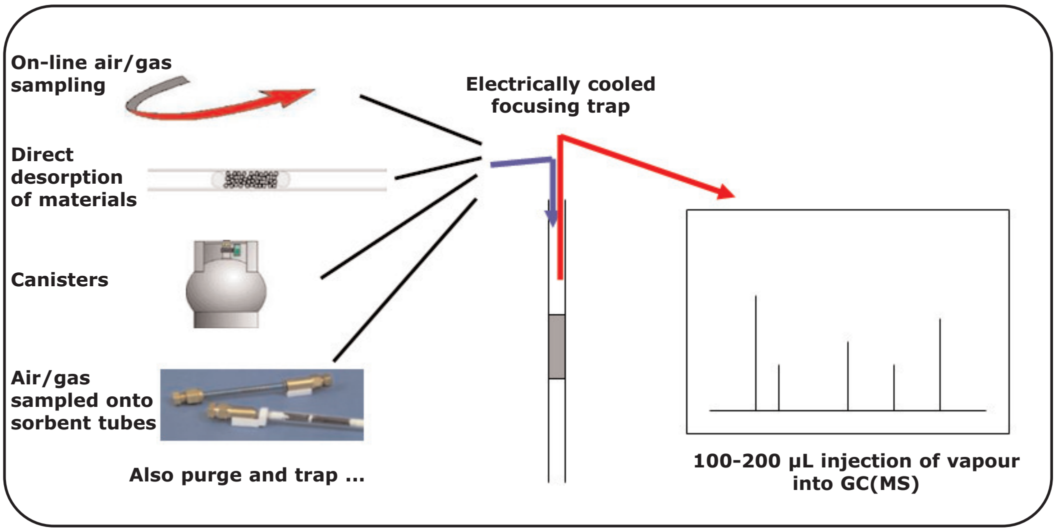


Figure 1: Schematic illustrating the single or multi-step process of thermal desorption

- Food, flavour, fragrance and odour profiling
- Materials emissions testing

However, despite the advantages it offers, thermal desorption on its own is not always enough to ensure reliable analysis of trace target compounds in the complex total ion chromatograms (TIC) produced from many real world samples. Chromatographic baseline or background anomalies such as; column bleed, extended solvent tails, air/water interference and unresolved sample matrix components, can all make it difficult to confidently identify and accurately measure trace toxic and odorous species present at the lowest levels of interest.

A new GC/MS data reprocessing software package called **ClearView™**, has been introduced by Markes International, which uses an innovative mathematical approach to distinguish and eliminate background interference from real chromatographic peaks, even at the lowest levels. This should be of tangible benefit to typical TD-GC/MS 'needle-in-haystack' applications. ClearView can be applied to archived TIC data from leading brands of GC/MS. Its potential advantages to thermal desorption and trace GC/MS applications generally, have been evaluated and are reported here with examples.

Introducing ClearView

ClearView uses a sophisticated software algorithm to accurately and dynamically compensate for chromatographic background as it changes throughout a run. ClearView is able to distinguish real chromatographic peaks, however small, from the background signal as it changes throughout a run. It can thus compensate accurately for the background without compromising any chromatographically-relevant information. It can be applied to total ion or extracted ion data. An example of its application to TD-GC/MS data (quadrupole MS in this case) is shown in figure 2.

Figure 2 shows the TD-GC/MS analysis of a landfill gas standard carried out using an ULTRA-UNITY automated TD system (Markes International) with a thick-film, high-bleed column and quadrupole MS. The TIC trace is shown both before and after ClearView reprocessing. The dramatic impact on the baseline is immediately apparent, but what the TIC data doesn't show is the equally dramatic impact on spectral purity and signal to noise. Figures 3 and 4.

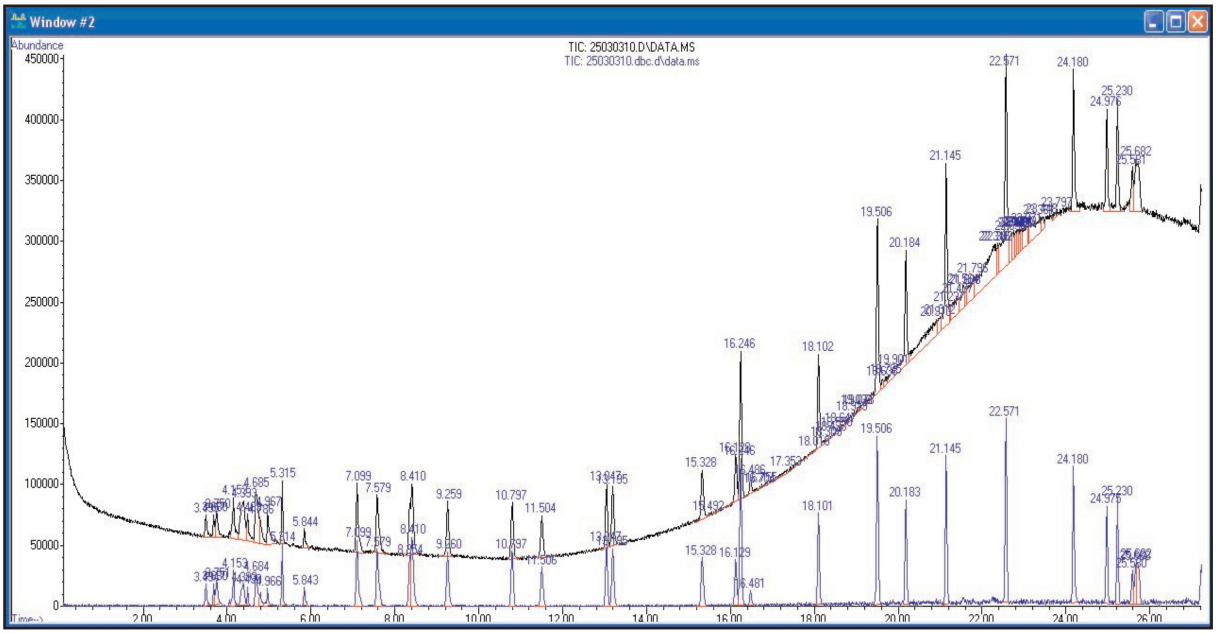
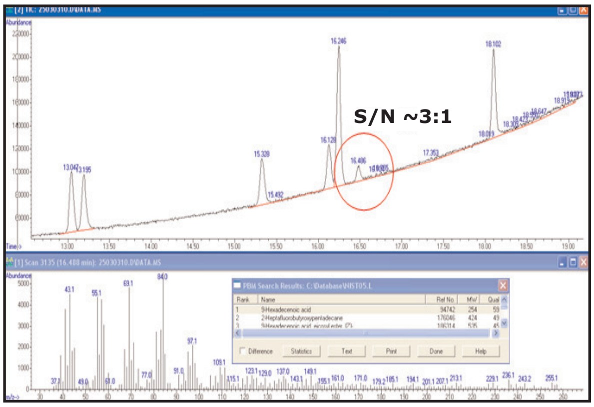
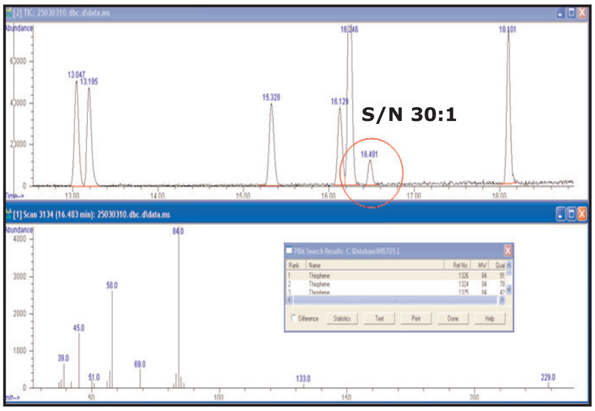


Figure 2: TD-GC/MS analysis of a landfill-gas standard using a thick film capillary column with high bleed. Original TIC data shown (black) and ClearView reprocessed data (blue)



PBM Search Results: C:\Database\NIST05.L

Rank	Name	Ref No.	MW	Qual
1	9-Hexadecenoic acid	94742	254	59
2	2-Heptafluorobutyroxypentadecane	176046	424	49
3	9-Hexadecenoic acid, eicosyl ester, (Z)-	186314	535	45



PBM Search Results: C:\Database\NIST05.L

Rank	Name	Ref No.	MW	Qual
1	Thiophene	1326	84	91
2	Thiophene	1324	84	78
3	Thiophene	1325	84	42

Figure 3: Automatic analysis of the original GC/MS data file does not correctly identify the trace component at 16.486 mins because high level background ions interfere with the mass ion fragmentation (MIF) pattern

Figure 4: Automatic analysis of the ClearView reprocessed data file shows greatly enhanced spectral purity allowing automatic identification of this trace component as thiophene

Discussion of sensitivity enhancement

By minimising GC/MS background ion contributions ClearView reduces noise thereby increasing signal to noise (S/N) ratios (*i.e.* sensitivity) in full scan mode. In the above example, thiophene has a S/N ratio of ~3.0 (RMS) in the original GCMS data file (Figure 3) versus a S/N of ~30 in the ClearView reprocessed data file (Figure 4).

In addition to improving S/N ratios, ClearView can also facilitate an increase in actual signal levels for many real-world samples. This can be explained using the example shown above.

For reasons of selectivity, response factors for individual compounds are typically calculated based on a single target ion within the mass ion fragmentation (MIF) pattern of interest. The mass ion selected is typically only one of many generated during the ionisation process and may not even be the most significant in the ion in the fragmentation pattern (spectrum). This means that, in many cases, only a small proportion of the MIF is actually being used for quantitative analysis. In contrast, by minimising background ions, ClearView expands the choice of mass ion selection for quantitation to encompass potentially the entire MIF profile, a range of ions, or a summation of specific mass ions.

Examining the MIF pattern for the peak at 16.486 minutes in figure 3, it is clear that, due to the high background at this point in the total ion chromatogram, quantitation of thiophene in the original GC/MS data file would require single extracted ion analysis using parent mass ion 84. The number and range of interfering mass ions precludes use of a mass range for quantitation in this case.

In contrast to this, it is clear from figure 4 that masses ranging from around 30 to 84 amu could be used for thiophene quantitation in the ClearView reprocessed data. In this actual example, the extracted ion profile for mass 84 has a peak area of 144112, whereas using mass range 30-84 for quantitation gives an area of 395085. This represents nearly 3-fold increase in actual signal/peak area.

Chromatographic ‘needles’ in TIC ‘haystacks’

The use of ClearView for enhancing the identification of even lower level compounds is illustrated below using an example of trace contaminants in pure air. In this case 500 ml of clean outdoor air was sampled and analysed using on-line thermal desorption (series 2 UNITY-Air Server) with GC/MS. TOF MS was used in this case. Original and ClearView reprocessed data are shown below (Figure 5) with a close-up of the area of the TIC around 12.6 minutes shown in figure 6.

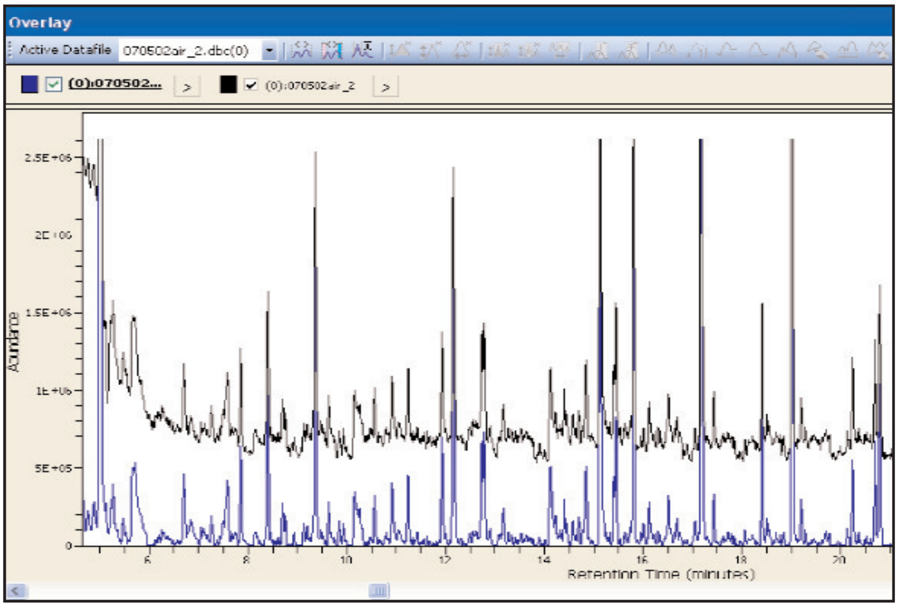


Figure 5: 500 ml outdoor air sampled on-line. Original GC/MS data (black). ClearView reprocessed data (blue)

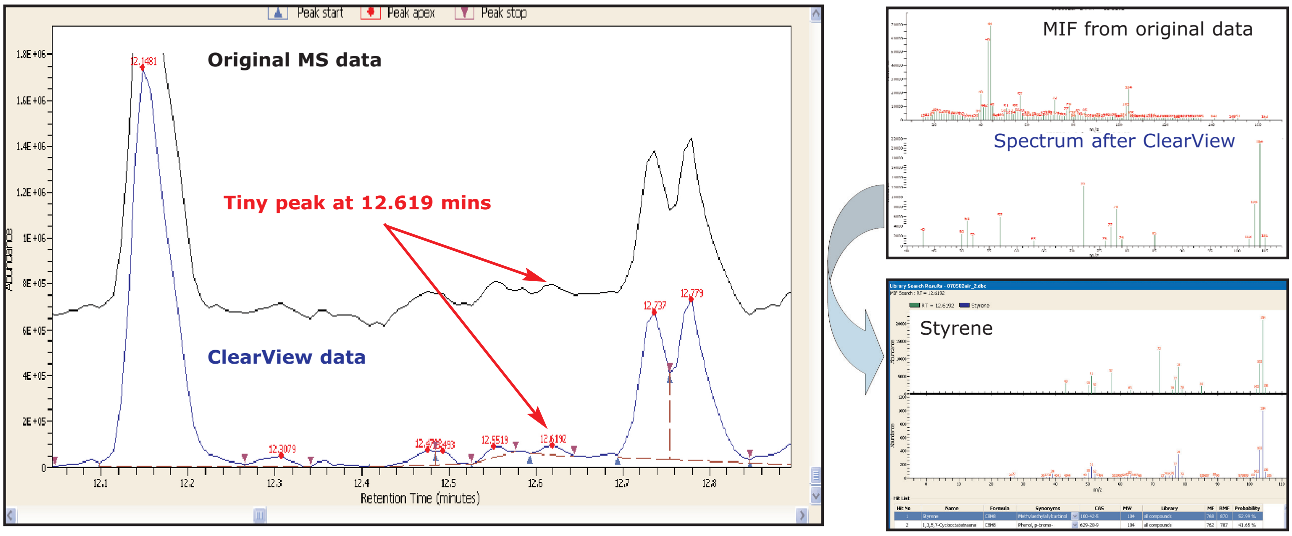


Figure 6: Close-up of original and ClearView reprocessed data at around 12.6 minutes. Insets: High mass ion interference in the original data file meant no identification was possible. Much lower mass ion interference in the ClearView reprocessed data allowed automatic library search identification of styrene.

As shown, identification of this trace level styrene peak was not possible by automatic library searching using the original data file, but was readily achieved using the ClearView reprocessed data file.

Discussion of potential improvements in quantitative accuracy and repeatability

In order to evaluate the quantitative accuracy and repeatability of ClearView, the software was presented with a particularly challenging GC/MS application – high speed analysis of diesel fuel (5 minute total run time) containing trace levels (3 pg on column) of octafluoronaphthalene (OFN). A Time-of-Flight (TOF) mass spectrometer was used in this case. Figure 7 shows the original GC/MS data file overlaid with the ClearView reprocessed data file. Once again the impact of ClearView in terms of flattening baselines (this time by removing the 'hump' of unresolved sample matrix components) can be clearly seen. The process of flattening the baseline alone facilitates more accurate and repeatable automatic integration.

[Note that ClearView reprocessing does not over-write the original GC/MS data file. The ClearView reprocessed data is stored as a separate and additional data file.

The original GC/MS data is left intact and uncompromised and can be used to compare or qualify ClearView data whenever required. The data shown in figure 7 is an example of an application in which both the original and the ClearView reprocessed data file are required. The original GC/MS data file is necessary to allow integration of the total peak area for simulated distillation-type calculations whereas the ClearView reprocessed data file facilitates more accurate/repeatable analysis of the resolved components.]

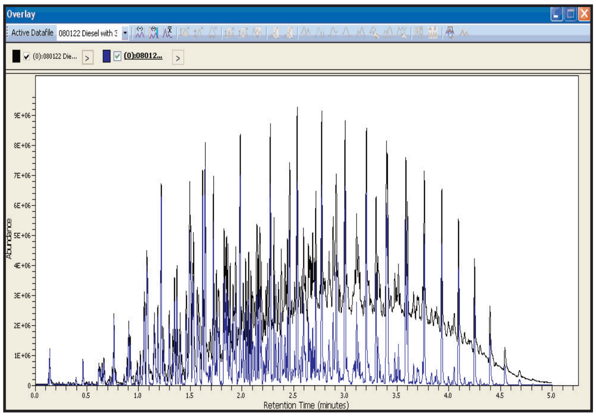


Figure 7: TIC analysis of trace levels (3 pg on column) of octafluoronaphthalene (OFN) in diesel using high speed chromatography and Time-of-Flight (TOF) MS. 5 min run time. Original GCMS data (black) shown overlaid with ClearView reprocessed data (blue)

In order to assess any potential negative impact of ClearView on the mass ions contributing to chromatographically resolved peaks, the same data (original and ClearView reprocessed) were first examined in extracted ion mode.

While the trace octafluoronaphthalene (OFN) signal is buried within the diesel matrix in the TIC trace (Figure 7) and cannot be detected, its presence and retention time can be confirmed by extracting the key mass 272 ion (Figure 8). Detailed close comparison of the OFN extracted ion signal from the original data file and the ClearView reprocessed file shows that the peak area data is *identical*. This indicates that no mass data contributing to the chromatographic peak is lost during ClearView reprocessing and that full quantitative consistency with the original data has been maintained.

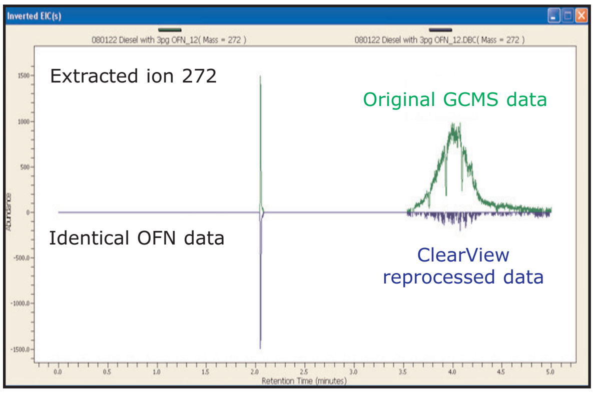


Figure 8: Diesel/OFN data in extracted ion mode (the match between the OFN 272 signals - original and ClearView reprocessed data - is so perfect that they are inverted for clarity)

Such quantitative consistency cannot be claimed for conventional static background subtraction methods - as used by many MS software systems to reduce background contribution to a TIC profile. The limitations of static background subtraction are illustrated below in figures 9 and 10.

Figure 9 show the extracted mass ion 273 data (original and ClearView reprocessed) for the C_{13} isomer of OFN. The ^{13}C isomer of OFN has a natural abundance of only ~11% relative to the normal ^{12}C isomer so this result for 3 pg of OFN on column indicates femtogram sensitivity for the TOF-MS. Despite working at these super-trace levels, close examination of the original and ClearView reprocessed data once again show an identical response *i.e.* ClearView reprocessing has not compromised the mass ion data contributing to the OFN peak area at 2.084 minutes. However, later in the chromatogram (from about 3.6 minutes) the positive impact of ClearView in removing the contribution of background 273 mass ion present in the unresolved diesel matrix can be seen.

If, alternatively, a conventional static mass ion fragmentation (MIF) background subtraction is performed at 4.2 minutes and applied to the original GC/MS data file then the broad hump maximising at this time can be reduced to something similar to that seen in the ClearView profile (Figure 10). However, the OFN peak at 2.084 minutes completely disappears under these conditions highlighting the limitations of static subtraction.

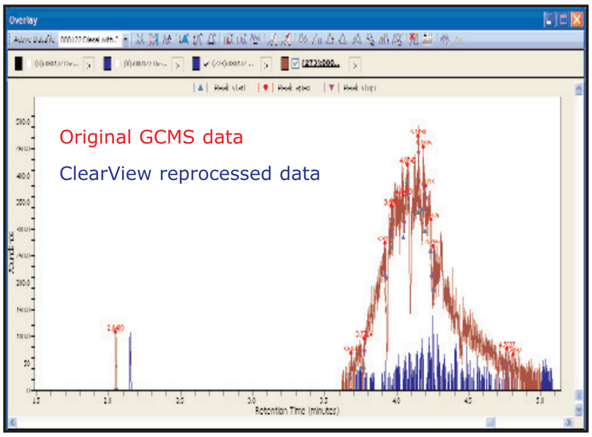


Figure 9: Overlaid extracted ion (mass 273) ^{13}C **chromatograms (original and ClearView reprocessed) from the high-speed GC-TOF analysis of diesel spiked with 3 pg OFN. Data offset by 5% along the x axis for clarity**

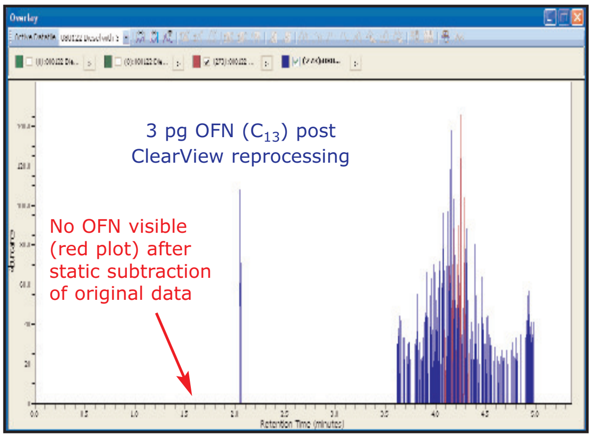


Figure 10: Overlaid extracted ion (mass 273) ^{13}C **chromatograms (ClearView reprocessed (blue) and static background subtraction (red)) from the high-speed GC-TOF analysis of diesel spiked with 3 pg OFN. As above, data offset by 5% along the x axis for clarity**

Other quantitative advantages of ClearView (improved integration and run-to-run reproducibility) are illustrated below (Figures 11 and 12).

Figure 11 shows the ClearView reprocessed data from three consecutive high speed GC-TOF analyses of OFN-spiked diesel injected manually. A region of interest is highlighted in the upper plot, and is shown expanded to full-scale below. Visual inspection of the overlaid data in close-up shows the excellent run-to-run reproducibility obtained using ClearView.

This degree of repeatability makes it possible to reliably implement sophisticated, time-dependent, integration events within a data analysis method for application to all the runs in a data set. For example, note the integration event inserted within the TIC (see blue oval) for applying a 'free-hand' baseline between 3.1 and 3.17 minutes such that peak areas within this time window can be summed. The peak area reproducibility obtained was 4% RSD; remarkable for summed peaks and manual injection.

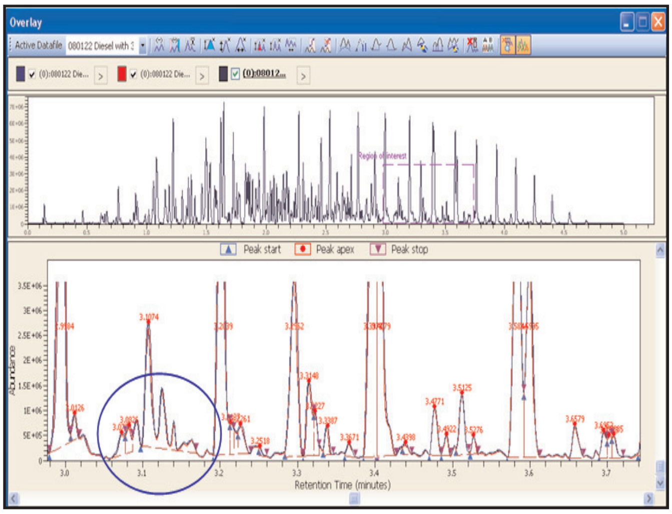


Figure 11: Three overlaid repeat high-speed GC-TOF MS analyses of OFN-spiked diesel, all reprocessed using ClearView. Full run (top), expanded area (bottom). Enhanced baseline assignment and repeatability shown.

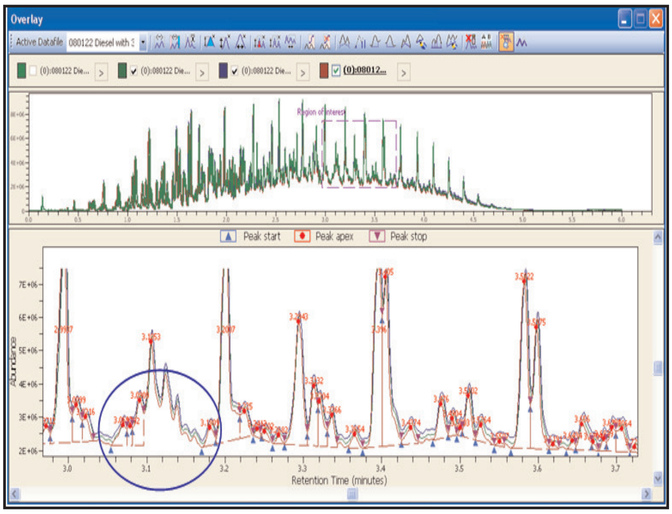


Figure 12: Overlay of the original GC/MS data from the series of 3 diesel/OFN analyses - as shown in Fig 11, but without ClearView reprocessing. The decrease in performance with respect to repeatability & chromatographic resolution are obvious

When the same data analysis method (*i.e.* incorporating the integration event for assigning a baseline and summing peaks between 3.1 and 3.17 minutes) was applied to the original GC/MS data obtained from this series of three runs (Figure 12), it had no effect. In other words, no baseline was constructed on any of the 3 original GC/MS data files.

When a second attempt was made to implement a timed integration event using one of the original GC/MS data files, a baseline was drawn for this one file. However, when this data analysis method was subsequently applied to the other two original GC/MS data files in the set, y-axis displacement (differences) between the runs meant it could not be implemented and no baseline was drawn.

As an aside, results from this part of the study indicate another benefit of ClearView – the degree to which it simplifies automatic integration thus reducing the requirement for expert manual data analysis post-run.

Impact on quantitative accuracy and repeatability when common ions are present?

As an ultimate challenge to the quantitative performance of the new algorithm, the landfill gas standard data (Figure 2) was used to evaluate how well ClearView performed when trying to discriminate background ion contributions from chromatographic data when the peak and background contained one or more common ions.

As an example, the peak at 18.02 minutes (butanethiol) was examined. The spectrum of butanethiol includes a contribution from mass ion 55 which was also present in the background. Figure 13 shows a spectrum obtained from the reprocessed data at the apex of the peak (which was confirmed as butanethiol by library search) and a spectrum from the background immediately after the peak. Both show a contribution from mass ion 55.

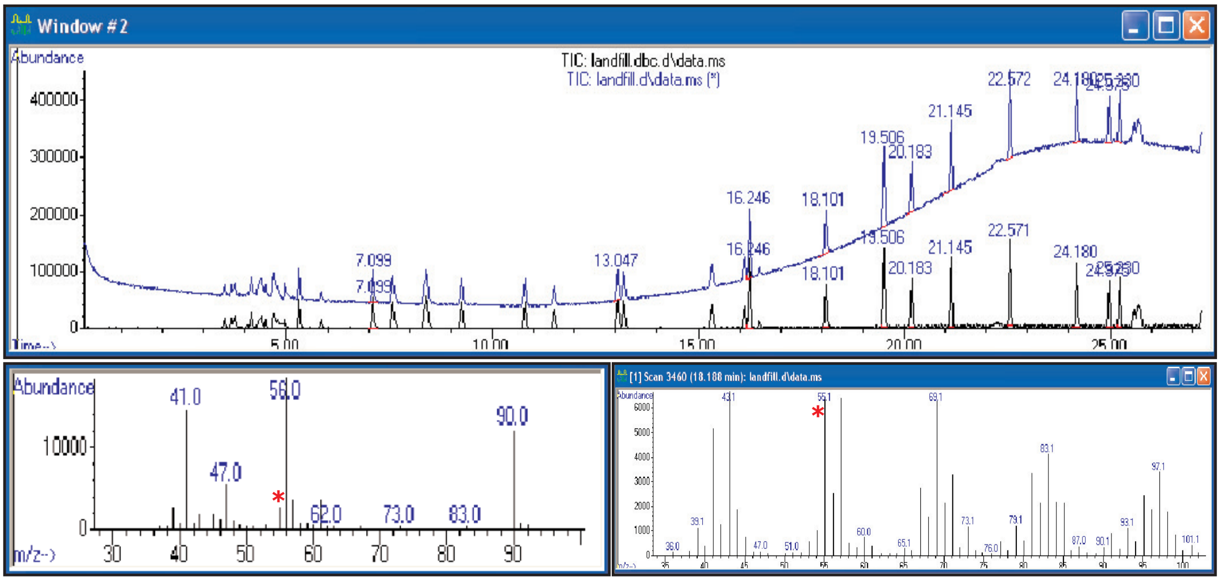


Figure 13: Original and reprocessed data files for the landfill gas standards, highlighting butanethiol at ~18.1 minutes, shown together with the peak apex spectrum from the reprocessed data and a spectrum of the background signal immediately after the peak in the original GC/MS data original and reprocessed data files for the landfill gas standards, highlighting butanethiol at ~18.1 minutes, shown together with the peak apex spectrum from the reprocessed data and a spectrum of the background signal immediately after the peak in the original GC/MS data

To evaluate whether ClearView had correctly compensated for the mass ion 55 contribution due to the background and eliminated it from the reprocessed data without impacting the contribution of mass ion 55 to the peak, the extracted ion 55 data (original and reprocessed) were overlaid with appropriate offset and alignment (Figure 14).

As mass 55 is a minor component of the butanethiol spectrum, any loss during reprocessing would be immediately apparent. However, the degree of correlation was remarkable, indicating that ClearView to compensated accurately for the background, without compromising chromatographic data, even when common ions were present.

Increasing the scanning mass range and reducing air/water interference

Another key issue for trace TD-GC/MS work can be air and water interference. Monitoring trace atmospheric concentrations of key ultra-volatile pollutants such as freons and C_2 hydrocarbons, requires use of super-strong, non-hydrophobic sorbents such as carbon molecular sieves which can retain significant masses of water and traces of carbon dioxide during environmental air monitoring. The impact of these interferences can usually be reduced by judicious use of dry purging both before and during thermal desorption. However, traces may remain and cause baseline anomalies, particularly in the first part of the total ion chromatogram.

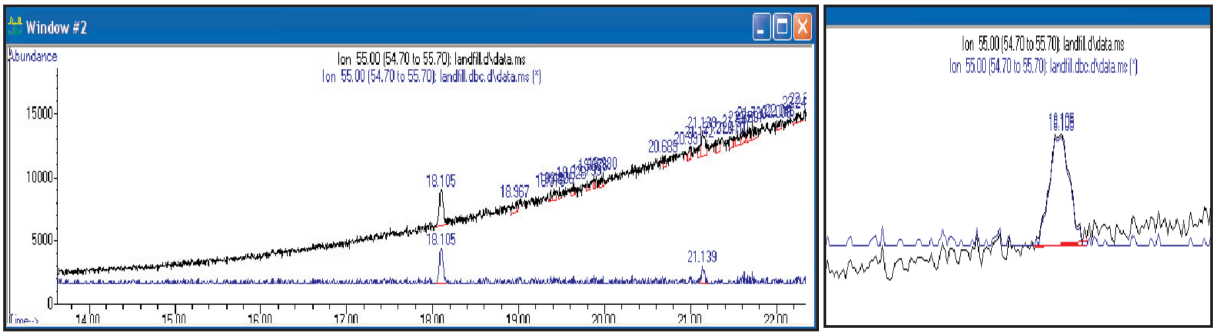


Figure 14: Extracted ion data for the original and reprocessed data. The overlaid trace was obtained by offsetting and aligning downwards the extracted ion response in the original data to match that in the reprocessed data

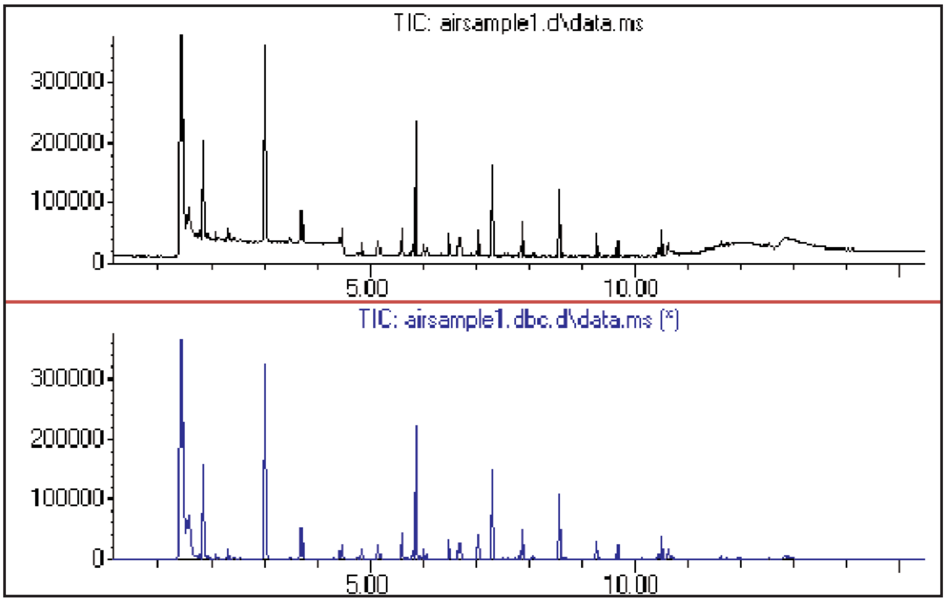


Figure 15:

TD-GC/MS of humid air sample scanned from mass 15. Original GC/MS data file (black) and ClearView reprocessed data (blue)

In extreme cases, these perturbations can become significant and may compromise quantitative analysis when scanning below mass 45 (Figure 15). However, when studying light compounds it is not always possible/ advisable to exclude mass ions below 45. Low mass ions may comprise a major part of the spectrum of the light compounds of interest and their exclusion may compromise the match quality of some key target analytes.

As with the other forms of chromatographic interference described above, ClearView can be used to reduce the impact of air and water interferences and facilitate scanning from low masses. Figure 15 shows the impact of ClearView on a worst case example; The TD-GC/MS analytical data of a humid air sample, collected using non-hydrophobic (strong) sorbents, desorbed with insufficient dry purging and scanned from mass 15.

Summary

This paper has illustrated the potential of ClearView to enhance the quality of GC/MS data for trace components, which is a critical issue for many key thermal desorption applications. Improvements in spectral purity have been shown to facilitate more automated/higher quality identifications of trace components while at the same time flatter baselines and reduced interference have been demonstrated to offer more sensitivity and more repeatable quantitative analysis without any loss of ‘peak’ area data. It has also been shown to enable scanning from low masses.

By reducing the need for time-consuming manual re-integration of complex total ion chromatograms by skilled GCMS technicians, ClearView also offers a significant potential reduction in mean time/cost-per-analysis while simultaneously improving the quality of GCMS data obtained (quantitative and qualitative).

Trademarks

ClearView™ is a trademark of Markes International Ltd., UK

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