

# Analysis of complex phthalate mixtures by GC-TOF MS with Select-eV soft ionisation

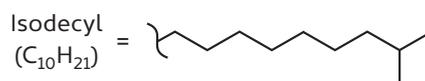
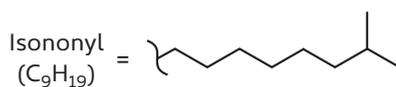
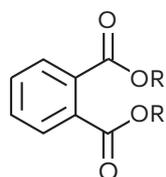


This study shows how the acquisition of 'soft' electron ionisation spectra offers significant advantages for the GC-MS analysis of phthalates. In particular, we show that the increased intensity of high- $m/z$  ions allows discrimination between symmetrically-substituted phthalates and those with two different alkyl chains, for improved understanding of the constitution of complex phthalate mixtures used in consumer goods and industrial products.

## Introduction

Esters of phthalic acid, known as phthalates (Figure 1), are used as plasticisers in a variety of polymer-based consumer goods and industrial products. However, phthalates readily enter the food chain and the wider environment, and this, coupled with concern over their potential endocrine-disrupting effects, has led to regulatory action, including a 2005 EU Directive<sup>[1]</sup> and the 2008 US Consumer Product Safety Improvement Act.<sup>[2]</sup> Both of these relate to the constituents of children's toys, and as well as entirely banning the use of certain lower-boiling phthalates, place precautionary restrictions on some longer-chain phthalates.

As a result of such action and growing public awareness of the issue, manufacturers have over recent years been shifting towards the use of these higher-boiling phthalates. However, technical-grade phthalates are often highly complex mixtures that may contain branched-chain isomers, or congeners with different-length alkyl chains. For example, the chemical with CAS No. 68515-48-0, known as diisononyl phthalate (DINP) actually contains various phthalic acid diesters with branched  $C_8$ - $C_{10}$



**Figure 1**

The general structure of phthalates, and the alkyl groups that are discussed in this article. The longer-chain technical-grade phthalates are listed as having  $R = R'$ , but usually contain isomers or homologues.

chains,<sup>[3]</sup> in addition to the specific chemical compound with that IUPAC name (CAS No. 28553-12-0).

Such issues mean that standard GC separations often struggle to achieve complete resolution of phthalates used industrially. This impedes the process of regulatory compliance by causing products to unexpectedly fail analytical tests, and also makes it difficult to obtain a clear understanding of the impact on phthalate-containing products on health. There is therefore a need for an analytical system that can identify the broad distribution of homologues present within phthalate mixes (and preferably speciate individual isomers).

Gas chromatography–mass spectrometry (GC–MS) is widely used to analyse phthalates, but conventional electron ionisation (EI) at 70 eV causes a high degree of fragmentation. The result of this is mass spectra that are dominated by an ion that has lost both the alkyl chains ( $m/z$  149), with the higher-molecular-weight ions that are vital for confident identification of isomers giving weak signals.

In this study, we show how Select-eV<sup>®</sup> technology<sup>[4]</sup> for BenchTOF<sup>™</sup> time-of-flight mass spectrometers can address this problem, by providing soft EI spectra that retain structurally significant ions, alongside conventional reference-quality 70 eV spectra.<sup>[5]</sup>

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## Experimental

**Sample preparation:** 50,000:1 dilutions in dichloromethane were prepared for two technical-grade phthalate ‘fractions’ labelled DINP and DINP-S, both reported to contain diisononyl phthalate isomers as their major components.

**GC:** Instrument: 7890B (Agilent Technologies); Injector: Split/Splitless injector at 280°C; Liner: 4.0 mm i.d. liner, 1 µL injection; Carrier gas: Helium, constant flow at 1.4 mL/min; Mode: Pulsed splitless, 30 psi for 0.7 min, purge at 50 mL/min; Septum purge: 3 mL/min; Column: BP5MS<sup>™</sup>, 30 m × 0.25 mm × 0.25 µm; Temperature program: 40°C for 1 min, then 150°C/min to 275°C (0 min), then 1°C/min to 285°C (0 min), then 50°C/min to 330°C (2 min); Run time: 15.5 min.

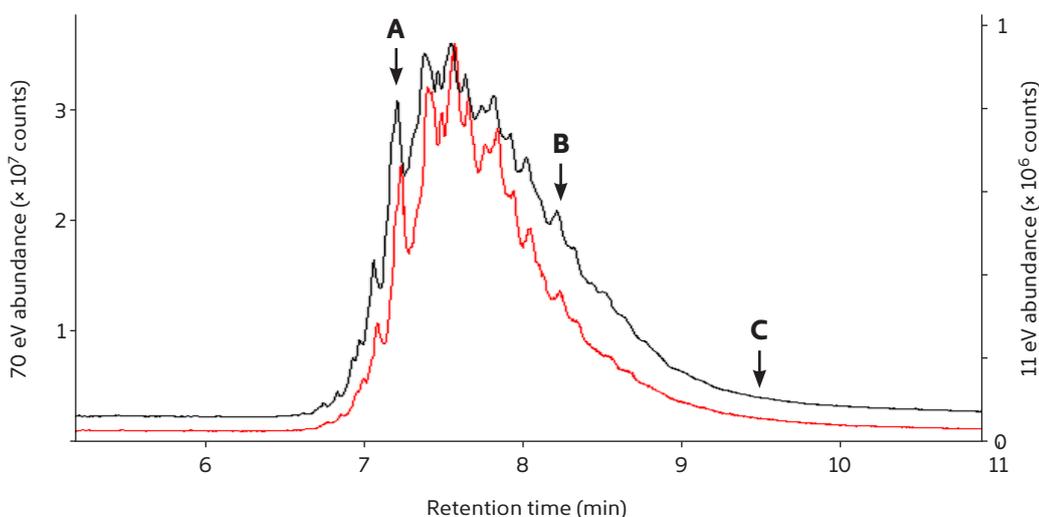
**TOF MS:** Instrument: BenchTOF-Select<sup>™</sup> (Markes International); Filament voltage: 1.8 V; Ion source: 250°C; Transfer line: 330°C; Mass range:  $m/z$  35–600; Data rate: 4 Hz; Ionisation energy: 70 eV and 11 eV.

**Software:** TOF-DS<sup>™</sup> (Markes International).

## Results and discussion

### Analysis of technical-grade DINP

The four phthalate 'fractions' were analysed using GC-TOF MS to generate electron ionisation spectra at 70 eV and 11 eV. Figure 2A shows technical-grade diisononyl phthalate (DINP) run at the two energies, showing the reduced level of background noise at 11 eV, which is a consequence of the lower degree of fragmentation undergone by the molecular ion. The fact that this technical-grade material is a complex mixture of many compounds is evident from the broad hump in the chromatogram, which took over 2 minutes to elute.



**Figure 2**

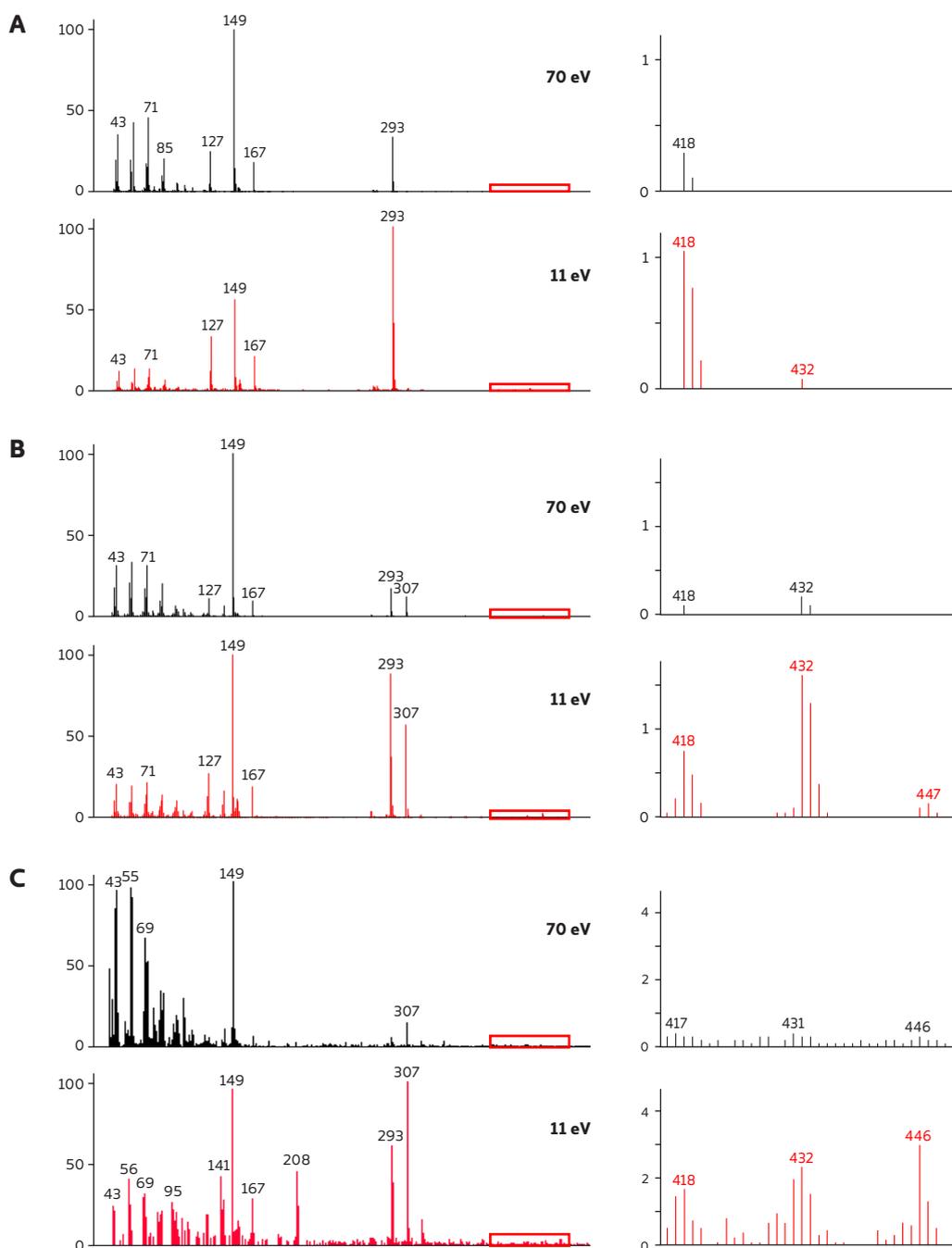
Analysis of technical-grade DINP at 70 eV (black) and 11 eV (red), showing the highly complex nature of this mixture. The arrows indicate the retention times from which the spectra shown in Figure 3A-C are derived. Note the reduced level of noise at 11 eV, which more than compensates for the reduction in sensitivity that would otherwise result from the lower response at this ionisation energy.

### Mass spectra acquired from technical-grade DINP

Inspection of the mass spectra (Figure 3) at three retention times in the chromatogram of technical-grade DINP reveals significant differences between the acquisitions at 70 eV and 11 eV. The 70 eV mass spectra of phthalates normally have  $m/z$  149 as the most abundant ion,<sup>[6]</sup> but the universal presence of this ion, which does not contain any alkyl chains, means that it is of very limited use for identifying phthalates.

However, the 11 eV spectra show clear differences in ion abundance that make them particularly useful for identification of phthalate homologues. In particular, there is an increase in the abundance of ions at higher  $m/z$  values, reflecting the reduced degree of fragmentation expected with soft ionisation. This reduced fragmentation also leads to a diminished abundance of low- $m/z$  fragments (especially below  $m/z$  149), which reduces spectral noise and so increases sensitivity.

Figure 3A shows the spectra at a retention time of 7.20 min. The most abundant ion in the 11 eV spectrum is  $m/z$  293, which corresponds to a molecular ion that has lost one alkyl chain, and there is also an increase in the abundance of the ion at  $m/z$  418, corresponding to the molecular ion. Both these facts help to confirm the identity of the major component as dinonyl phthalate.<sup>[7]</sup>



**Figure 3**

Mass spectra acquired at 70 eV (top, black) and 11 eV (bottom, red) at retention times of (A) 7.20 min, (B) 8.25 min and (C) 9.48 min.

This increase in the intensity of ions containing alkyl chains makes it much easier to ascertain when a phthalate with a different alkyl unit is present. Figure 3B shows the spectra at a retention time of 8.25 min, and in this case there is an increase in intensity of an ion at  $m/z$  307 (14 units higher than  $m/z$  293). This indicates an isomer with one more  $\text{CH}_2$  unit in the  $(M - \text{alkyl})^+$  fragment, i.e. with a  $\text{C}_{10}$  rather than a  $\text{C}_9$  chain. The *initial* assumption from this might be that the analyte in question is didecyl phthalate, and indeed this is the compound that has the strongest match in a comparison of the 70 eV spectrum against the NIST 14 library.

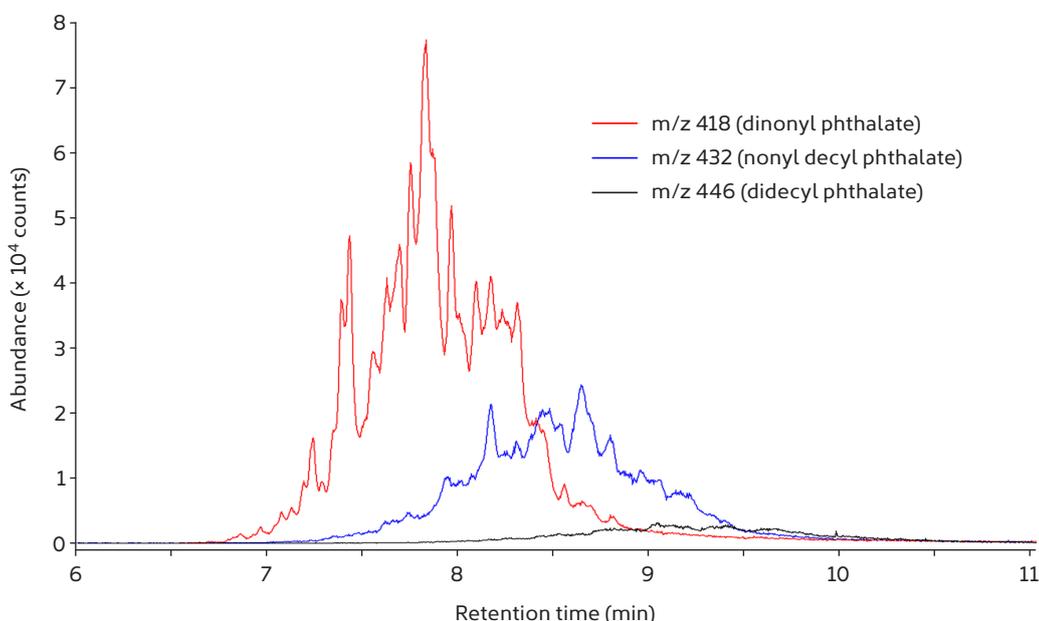
However, the increased sensitivity of the soft ionisation technology used in this study means that we arrive at a slightly different conclusion. The presence of an ion at  $m/z$  432 (but not at  $m/z$  446) in Figure 3B suggests that the main compound eluting at this retention time is actually a mixed diester, namely nonyl decyl phthalate. Such a finding would likely have been missed using conventional 70 eV spectra, because of the very weak molecular ion.

For comparison, Figure 3C shows the spectra at a retention time of 9.48 min. In the 11 eV spectra, the intensities of the pair of  $(M - \text{alkyl})^+$  ions has shifted further in favour of  $m/z$  307 (relative to  $m/z$  293), and there is now a significant peak at  $m/z$  446. Both these facts indicate the presence of didecyl phthalate, and as before, this conclusion can be reached with a degree of confidence that would not be possible by relying solely on the 70 eV spectra.

This increase in intensity of the molecular ion at 11 eV also improves quantitation, which with phthalates normally relies upon the  $(M - \text{alkyl})^+$  ion. As shown above, if mixed diesters are present, this is unreliable, because this ion could arise from fragmentation of more than one homologue. The soft ionisation technique used here allows the analyst to use the molecular ion as the quantifier ion, with the  $(M - \text{alkyl})^+$  and the phthalic anhydride ( $m/z$  149) fragment as qualifiers.

### Extracted-ion chromatograms for technical-grade DINP

A useful way of visualising the gradual shift from nonyl- to decyl-substituted phthalates with increasing retention time is to overlay the extracted-ion chromatograms corresponding to the molecular ions (Figure 4). Doing this makes it clear that the majority of the fraction comprises dinonyl phthalate, and that most of this elutes before 8.2 min. Eluting later is a significant amount of nonyl decyl phthalate, while didecyl phthalate is present in small quantity.

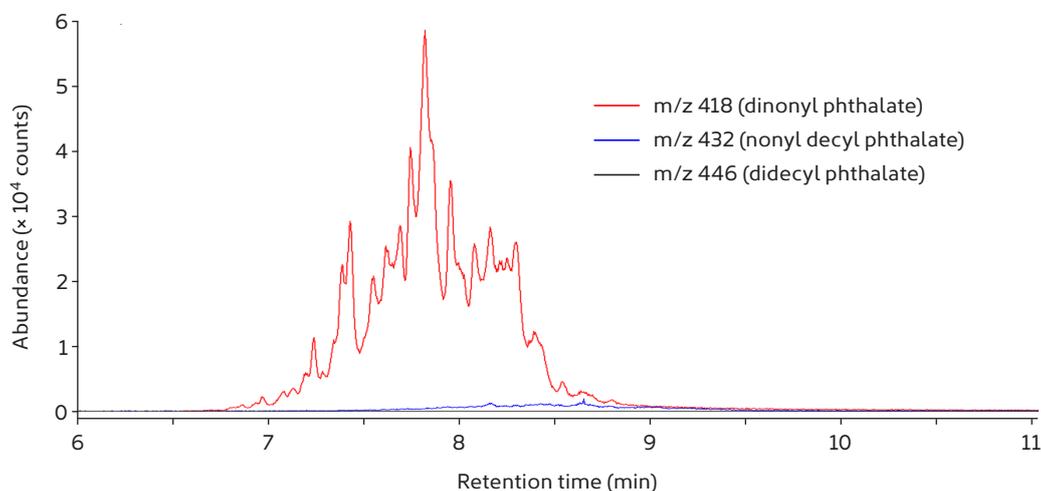


**Figure 4**

Analysis of technical-grade DINP at 11 eV showing extracted-ion traces for the molecular ions of three phthalate homologues.

## Extracted-ion chromatograms for technical-grade DINP-S

Analysis of the DINP-S fraction was carried out in the same manner as for DINP (Figure 5), and shows a much higher proportion of dinonyl phthalate, a much lower proportion of nonyl decyl phthalate, and a negligible quantity of didecyl phthalate.



**Figure 5**

Analysis of technical-grade DINP-S at 11 eV, showing extracted-ion traces for the molecular ions of three phthalate homologues.

## Conclusions

This study has shown how Select-eV technology for BenchTOF time-of-flight mass spectrometers offers significant advantages for the analysis of phthalate mixtures. In particular, we have shown that the reduced intensity of low-m/z ions reduces spectral noise, giving increased sensitivity, while the increased intensity of high-m/z ions allows discrimination between (and quantitation of) symmetrically-substituted phthalates and those with two different alkyl chains.

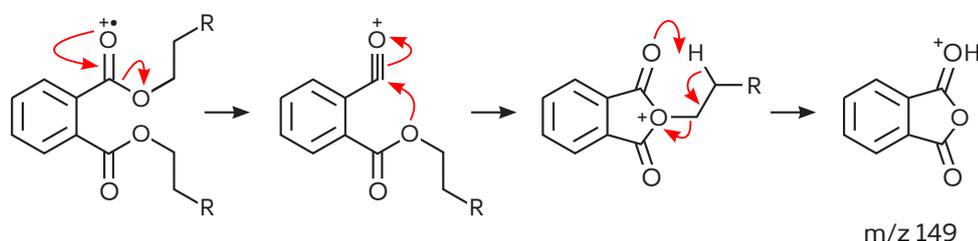
Select-eV offers these advantages while avoiding the need for instrument down-time that is required for other soft ionisation methods such as chemical ionisation (CI). This is in addition to the inherent advantages of TOF mass spectrometry, namely the ability to achieve 'SIM-like' sensitivity for the entire analysis, and over the full mass range. The elimination of the need for SIM windows also makes method set-up easier, and means that there is no restriction on the number of analytes that can be monitored in a given time-frame.

Although this study has shown significant advantages for the identification of phthalates, there is scope for taking this further, for example by coupling soft-ionisation TOF MS to GC×GC, for even greater analytical resolving power and confidence in compound identification.

For more information on this application, or any of the techniques or products used, please contact SepSolve.

## References and notes

- [1] Directive 2005/84/EC of the European Parliament and of the Council of 14 December 2005, <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=URISERV:l32033>. The chemicals banned were bis(2-ethylhexyl) phthalate, dibutyl phthalate and butyl benzyl phthalate, while the use of di-n-octyl phthalate, diisononyl phthalate and diisodecyl phthalate was restricted to products that cannot be placed in children's mouths.
- [2] An act to establish consumer product safety standards and other safety requirements for children's products and to reauthorize and modernize the Consumer Product Safety Commission (H.R. 4040), US Congress, 2008, [www.congress.gov/bill/110th-congress/house-bill/4040](http://www.congress.gov/bill/110th-congress/house-bill/4040). The bill sets out the same restrictions as in the above EU Directive.
- [3] European Union Risk Assessment Report: 1,2-Benzenedicarboxylic acid, di-C<sub>8-10</sub>-branched alkyl esters, C<sub>9</sub>-rich and di-"isononyl" phthalate (DINP), European Chemicals Bureau, 2003, [www.echa.europa.eu/documents/10162/83a55967-64a9-43cd-a0fa-d3f2d3c4938d](http://www.echa.europa.eu/documents/10162/83a55967-64a9-43cd-a0fa-d3f2d3c4938d).
- [4] Select-eV capability, available on the BenchTOF-Select mass spectrometer from Markes International, allows soft EI spectra to be collected down to 10 eV, and is fully automated by the instrument's software with no inherent loss in sensitivity or need for manual intervention. These spectra provide enhanced molecular and structurally-significant ions to aid the identification of compounds that exhibit similar spectra (or extreme fragmentation) when using conventional 70 eV settings. Now available with the BenchTOF-Select is Tandem Ionisation<sup>®</sup> mode, which allows soft and hard ionisation spectra for a single peak to be simultaneously obtained, in both GC and GC×GC analyses, enabling challenging compounds (such as structurally similar isomers) to be discriminated without impacting laboratory workflows.
- [5] Uniquely among TOF MS instruments, the spectra generated by the BenchTOF systems used in this study are a close match to the quadrupole-acquired spectra in commercial libraries such as NIST or Wiley.
- [6] The presence of the m/z 149 ion in the EI mass spectra of all phthalates (except dimethyl phthalate) may be explained by the mechanism in Figure 6.



**Figure 6**

Possible route to formation of the m/z 149 fragment (protonated phthalic anhydride).

[7] In this discussion, we have used the terms 'nonyl' and 'decyl' to refer to alkyl chains with the formulae  $C_9H_{19}$  and  $C_{10}H_{21}$  respectively. Although the technical-grade phthalates we have studied here are listed as containing primarily isomers branched at the end of the alkyl chain (as shown in Figure 1), confident speciation of the precise mix of isomers involved would of course require much more complete chromatographic separation and in-depth analysis, which is outside the scope of this study.

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