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UPFRONT

Eau De Boeuf?

Plant-based burgers are on the rise, but how does their aroma compare to the real thing?

As plant-based meat alternatives become increasingly popular, food companies continue to pour time, money, and resources into creating the ultimate no-beef burger. But mimicking the taste, texture, appearance, and smell of the real thing is no mean feat. Now, researchers have used GC-MS to determine the quintessential "meaty" odor of a classic patty and pitted veggie alternatives against each other.

"During the last several years, increasing awareness of the impact of meat production on climate change, as well as meat shortages during the pandemic, have made people more accepting of plant-based alternatives," said principal investigator LiLi Zyzak in a press release (1). "There are a lot of products out there, and food companies are doing interesting research, but nobody ever publishes anything because it's a trade secret."

"The problem with plant-based burgers is that the plant protein itself contributes a strong odor," said Zyzak. "For example, pea protein smells like green, cut grass, so companies have to find a way to mask that aroma. Some use heavy seasonings."

The team started by comparing the odor compounds of plant-based burgers with those of the real thing. First, they cooked the various patties and simply described the smell – meaty, fatty, buttery, sweet, or roasted. Next, they used GC-MS (combined with olfactometry) to correlate the aromas with specific compounds. Volatiles were injected into the GC-MS and some diverted to a sniffing port where a person described the odor. The rest of the sample was then analyzed by MS to match specific compounds with each descriptor.

So who came out on top? Beyond Meat's burger most closely resembled the odor profile of a traditional hamburger, with compounds 1-octen-3-ol, octanal, and nonanal contributing to its meaty aroma. In the future, Zyzak plans to create a complete odor profile for beef burgers.

Reference

1. ACS (2021). Available at: https://bit.ly/3obn0Pt.

UPFRONT

Softening the Blow

Noble gas mass spectrometer monitors magma activity at volcano site – potentially providing early warning system that predicts eruptions

In 2014, Japan's Mount Ontake erupted unexpectedly, claiming the lives of 63 hikers. With no preceding earthquakes that might have warned authorities, the event spurred a tragic realization – a method to measure the progression of eruptions was vitally needed.

A team of researchers at the University of Tokyo, Japan, decided to explore whether the ratio of atoms in specific gases released from volcanic fumaroles could provide an indicator of what was happening to the magma deep below (1). Between 2014 and 2021, they measured isotopic compositions of noble gases in six fumaroles at Kusatsu-Shirane volcano in Japan. Noble gas mass spectrometry revealed that changes in the ratio of argon-40 and helium-3 can indicate magma frothiness – which, in turn, can signal the risk of different types of eruptions. To gain more perspective, we spoke to study co-author Tomoya Obase of Hokkaido University, Japan.

What were your main findings?

Understanding the state of magma is crucial for predicting volcanic activities, such as major eruptions. Our work revealed that, by analyzing volcanic gases, we can detect slight changes in magma activity that could not be detected by other volcano monitoring methods such as volcanic earthquake observation or crustal deformation.

Our method revealed significant changes in the magma-derived helium-3/argon-40 ratio, which is related to magmatic unrest. By modeling magma degassing processes, we revealed that the ratio reflects magma vesicularity, or how much the magma underground is foaming. Magma's vesicularity controls its buoyancy and the amount of magmatic gas provided to the hydrothermal system beneath a volcano. The former is related to magma ascent, which could potentially trigger an eruption; the latter is related to a risk of phreatic eruption, in which the water pressure in the hydrothermal system increases and causes an eruption. Therefore, our findings strongly suggest that the noble gas isotopic ratio is important for monitoring magma conditions related to volcanic activity.

Which analytical techniques did you use – and what were their advantages?

We used a state-of-the-art noble gas mass spectrometer that precisely measures noble gas isotopes and ultra-trace isotopes such as helium-3. Noble gases – including helium and argon – are chemically nonreactive, so noble gases in volcanic gas change their composition very little during ascent through the subsurface. This is greatly advantageous for gaining information about magma underground.

Were there any major challenges you had to overcome during the research?

Volcanic gas sampling in a field far from the laboratory is challenging, not only because it is time-consuming, but also because the sample is often contaminated by atmospheric gases before analysis. We tried to conduct our analysis as soon as possible after collection to avoid this problem.

It also takes a long time to analyze volcanic gas composition because gas samples must be brought back to the laboratory. Currently, we are developing a portable mass spectrometer for on-site analysis of noble gas isotope ratios in volcanic gas. On-site analysis has two advantages. First, it reduces the risk of atmospheric gas contamination, and second, it allows us to perform real-time monitoring. Portable mass spectrometry will help us detect, as early as possible, changes in magma activity that may be associated with future eruptions.

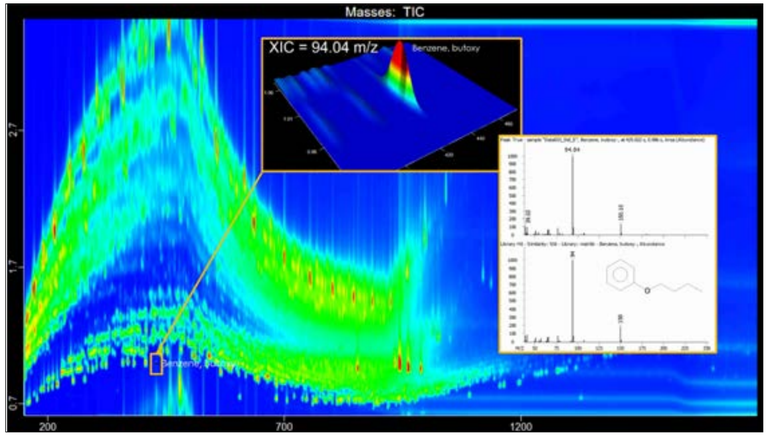
Reference

1. T Obase et al., Sci Rep, 12, 17967 (2022). DOI: 10.1038/s41598-022-22280-3.

APPLICATION NOTE

Battling Fuel Washing with the Pegasus® BT 4D

Accurate quantitation of ACCUTRACE™ Plus in commercial diesel and full characterization of petroleum samples



Total ion chromatogram (TIC) for BPE detection and mass spectral confirmation in a spiked commercial diesel B7.

Farm fuels are often government-subsidized due to their necessity in feeding the populace. To prevent these subsidized fuels from being resold to consumers at full price, they are often dyed to highlight their purpose. In 2017, the EU Decision 2017/74 approved "Solvent Yellow 124" (ACCUTRACE™ S10) as the common fiscal marker for gas oils and kerosene. However, common "fuel-washing" methods can remove the colorant and this marker, making it difficult to trace fuel back to its source and separate subsidized fuels from consumer products. In addition, the chemicals used to launder fuels creates serious environmental pollution as they get dumped as waste.

A new fuel marker, ACCUTRACE Plus, which is colorless, safer, and far more robust than ACCUTRACE S10, was evaluated and confirmed as its replacement, and its marking level has been set at a harmonized range to simplify the implementation across the entire European Union.

Fuel markers need to be detectable to be useful, and in the very congested chromatograms of petroleum products, a single analyte can be overwhelmed. With the GCxGC separation of the Pegasus® BT 4D, however, the ACCUTRACE Plus can clearly be identified and quantified in marker dosages as small as 1 percent. The fast acquisition rates (up to 500 spectra/s) acquire sufficient data points allowing for reliable quantitation. With a peak signal-to-noise (S/N) of ~100 at the lowest calibration level tested, the Pegasus BT 4D easily exceeds the required limit of quantitation in this sort of fuel analysis while simultaneously performing a detailed and comprehensive separation for full sample characterization.

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FEATURE

The (Long and Winding) Road to LPGC-MS

Jaap de Zeeuw, Hans-Gerd Janssen, and Steve Lehotay recall the origins of low-pressure GC, highlight the hurdles that sprung up during development, and discuss its relevance today

LPGC, when coupled to MS, is a fast and robust alternative to traditional GC-MS – but the concept of LPGC is not new; in fact, the low-pressure route towards faster GC has been known to analytical chemists since the 1960s. However, several challenges have stood in the way of its widespread adoption. In 2000, Jaap de Zeeuw injected (no pun intended) new life into LPGC with a simple solution – a restrictor that maintained positive inlet pressure for a wide-bore column.

Advocates of the technique have had to navigate a long and winding road fraught with obstacles, including technical challenges, commercial pressures, and dismissiveness from the analytical community. Today, LPGC-MS is accessible to all via a commercialized kit.

Here, three trailblazers on LPGC's journey – Jaap de Zeeuw, Hans-Gerd Janssen, and Steve Lehotay – share how the technique managed to persevere despite the hurdles and discuss where it might go next.

When did you first encounter LPGC?

Jaap: I guess I should kick this one off! The idea first occurred to me in around 1997 when I was thinking about MS and how it commonly uses long 0.25 mm columns. This is a logical choice when you need positive pressure in the injection port and the MS is running under vacuum – you need that length to have sufficient restriction. But, as I'm always looking for a challenge, I wanted to see if it was possible to use a wide-bore column with MS rather than the typical narrow-bore.

Based on the Van Deemter equation, I realized that – theoretically – at lower pressure a much higher optimal linear velocity could be obtained. I checked the literature for vacuum GC but saw that the setup being trialed was often challenging because the vacuum had to be created in the injection system. Instead, I proposed using pliers to restrict the flow on the inlet side of a metal 0.53 mm i.d. capillary. This approach led to a similar separation but an approximately nine times faster run time – and that simple idea was the basis of what we've continued to build upon with LPGC-MS to this day!

Steve: Let's see, my first email to Jaap was on February 25, 2000 – I had come across the title of a presentation that he made in Gifu, Japan, in November 1999, and Aviv Amirav had given me Jaap's contact info. In the email, I described how I had already made plans for a summer student, Katerina Mastovska, to investigate LPGC-MS with a quadrupole MS instrument. Interestingly, though, I first heard about "subambient pressure GC-MS" in 1989 from Mark Hail of Richard Yost's group at the University of Florida when we were both graduate students there.

Hans-Gerd: Well, the general concept has been around for a while – Carel Cramers, Piet Leclercq, and Jack Rijks started research into speeding up GC separations at Eindhoven University sometime in the 1970s. Cees Schutjes, the first PhD student in the field, defended his thesis in 1983, which included a theoretical treatise of the Golay equation. From this equation the increase of the mobile phase diffusion coefficients immediately followed as one route towards faster GC. When I started as a student in the Cramers' group in 1986, the thesis of Schutjes was standard information we all had to study. We also studied vacuum outlet conditions for their higher speed. But it was only around 1998 that we started doing experiments in low pressure GC, jointly with Jaap.

Did you immediately recognize the benefits of this technique?

Steve: I've always felt fortunate that I learned chromatography from John Dorsey at the University of Florida at the time. Being a great teacher, Dorsey always started each chromatography class with questions about his previous lecture. After spending weeks on the theory of chromatography with an emphasis to optimize separations and peak resolution, Dorsey began class one day by drawing a chromatogram on the chalkboard of two peaks with excellent resolution about two minutes apart. He then asked, "What's wrong with this separation?" He brushed aside the aspersions that his drawn peaks weren't perfectly Gaussian, and no one in the class saw a problem. He announced, "It's wasting time!"

I've never forgotten that moment or that concept, but it seems too many others have. I think too many chromatographers and mass spectrometrists forget that we are all analytical chemists. The specialist's mindset fixates on the power of chemical separations and not enough on practical matters of sample preparation, throughput, ease, cost, ruggedness, validation, and – above all – robustness. When I learned about Rapid-MS in 2000, I knew immediately that the restriction capillary was a brilliant idea and a solution for fast GC-MS. Having entered the "real-world" of pesticide residue monitoring in 1992, I recognized the benefits of LPGC very quickly. I was taught to always use a guard column in chromatography, and the idea to use the guard column also as a restrictor in LPGC was an elegant solution that I wish I had considered first!

Meet the LPGC Experts

Jaap de Zeeuw

Jaap de Zeeuwis currently an international specialist in GC at Restek Corporation. With 41 years of experience in GC capillary technology, he has developed many PLOT columns, developed the first bonded wax column, published more than 100 articles in the field of GC, and is the inventor of fast low-pressure GC using restriction at the inlet. Jaap also made the world's longest fused silica capillary, for which a Guinness World Record was granted. In 2016, he developed a new technique for coating PLOT columns based on SPIN deposition. Jaap has several hobbies, such as gardening, playing music, scouting, and helping out with his wife's B&B, and he is currently working on a program for teaching creative thinking to technical/analytical people.

"The larger instrument and column manufacturers are sometimes a bit risk averse, so even though Varian eventually recognized the value of LPGC, it took a while to develop."

Jaap: I immediately recognized the value of LPGC-MS, but some of those around me did not initially. Once I came up with my "simple solution," I proposed the idea to the management of Varian – the company I was working for at the time. They didn't take interest at first, so I wasn't able to do any experimentation. I then spoke to some of my esteemed colleagues – namely Carel Cramers, Aviv Amirav, and Hans-Gerd Janssen – and Varian became more interested with this expert backing. However, they decided it was more of an "academic" pursuit best left to the University of Eindhoven, and this is when Hans-Gerd and I began working together.

The initial protocol, based on the 0.53 mm capillary that had to be squeezed on one side using pliers, seemed really promising so we eventually filed for a patent – the initial design used a short 0.10 mm ID restriction (ca. 60 cm) coupled with a 10 m x 0.53 mm capillary. We worked with over 20 external groups who all came back with results showing the speed benefit of the columns. On top of this, it was clear that the technology would fit into many different application areas.

At this point, Varian took ownership of the product and decided to introduce it exclusively for the ion trap MS, with application in environmental trace analysis of pesticides and PCBs. I think this was a mistake – it took three years before this "Rapid MS" offering was also made commercially available because it didn't gain the expected revenue. Notably, the Rapid-MS instrument had a slower data acquisition rate than others, and I think this put a lot of people off.

Hans-Gerd: It's a good point Jaap makes here. The larger instrument and column manufacturers are sometimes a bit risk averse, so even though Varian eventually recognized the value of LPGC, it took a while to develop. Generally, I think the larger companies try to target scientists at conferences and hope that they will start to use the new technology and spread the word. That works, but is not a rapid route.

At Eindhoven University, we always had a massive interest in fast GC. Over the years we have helped many labs convert their regular GC to a faster run. Although we were mostly following the route of narrow-bore columns, it was clear that other options like very short columns, columns packed with very fast particles, or low-pressure outlet conditions also had their unique advantages. LPGC was always an option that people liked because it required only very small modifications to the equipment. Sometimes narrow columns are the preferred route, sometimes LPGC is better, sometimes both approaches work. But I'd say we very much recognized the benefits of LPGC-MS when it came along.

Meet the LPGC Experts

Hans-Gerd Janssen

Hans-Gerd Janssen has an MSc and PhD degree in analytical chemistry from the Eindhoven University where he studied and later worked in Carel Cramers' group. After working at Eindhoven University for almost 10 years as assistant and associate professor, he joined Unilever in 1999. Janssen has written more than 200 publications on theory and method development in chromatography and MS. From 2004 to 2019, he was a part-time professor at Amsterdam University, next to his position as senior scientist in analytical chemistry, focusing on food analysis, at Unilever R&D Wageningen. In 2019, he accepted a part-time professorship at Wageningen University where his research focuses on recognition-based analytical chemistry. Janssen holds positions in the editorial advisory boards of several journals and has served in various scientific and organizing committees for international conferences.

What additional developments led to the technique as it is today?

Jaap: In the first three years, there was a lot of noise in the market. Lots of people saw its potential and wanted to experiment with it – one such person in particular was Steve. During this period, I recognized some limitations in terms of the restriction lifetime/maintenance and the coupling, but never got the chance to work on that at Varian. However, when I joined Restek in 2008, I finally had the opportunity to try out different ways of making the restriction.

I came up with another simple solution based on making the coupling with PressFit and positioning this inside the injector body. This meant the coupling and restriction were always at high temperature and in an inert atmosphere. A publication was written and patent filed, but it never made it to a commercial product.

Steve: My colleagues and I had issues with the very narrow restriction capillaries in the Rapid-MS product. We ended up simply connecting two commercially available columns from any vendor (5m, 0.18 mm i.d. guard/restrictor capillary with a 15 m, 0.53 mm i.d., 1 µm film thickness analytical column), which provided both more robustness and theoretical plates. I reached out to all the GC vendors for 20 years about LPGC, and in 2021, Restek finally commercialized a product using our column dimensions.

Aside from this, there have been many technological advances in the past two decades to continually improve upon the performance and features of LPGC-MS. Most notably, commercial triple quadrupole MS/MS instruments were introduced, which provided greater targeted analyte detectability (both sensitivity and selectivity) and faster data acquisition speeds. High-resolution MS instruments have also been introduced, for which LPGC is compatible. Improvements of QuEChERS and analyte protectants streamlined sample preparation and improved peak shapes in GC. The development of a light and reliable capillary column union also helped make LPGC more practical for shipping and installation.

Who should consider LPGC-MS?

Steve: I think everyone that is using GC for analysis should consider LPGC-MS. My lab has used it routinely for nearly 20 years now. Why? Firstly, megabore columns are preferable in routine monitoring using GC because of their much greater sample loadability and robustness. LPGC is therefore very useful for rapid, sensitive, and robust analysis of pesticides, environmental contaminants, and pretty much any GC-amenable analyte that isn't too volatile. Secondly, LPGC as a product can be used as is in general applications, but, as a technique, it also possesses more parameters for investigation and innovation than standard GC-MS. For example, Amirav, Fialkov, and I recently published a paper (1) using resistive heating in LPGC-MS with a short 0.25 mm i.d. capillary column that achieved multiresidue analysis in <1 min. My long-term research plans are to implement such methods to enable ultra-fast monitoring without having to ship samples to a lab, for example. In the short term, one of my projects is to systematically evaluate LPGC-MS in food safety applications using different column dimensions.

Jaap: What we basically do with LPGC is trade efficiency for speed, but using a robust solution. As long as components that elute at the same retention time can be separated by MS, LPGC is useful. Of course, if isobaric components elute together it will not work. In that case, we need separation by chromatography using highly selective stationary phases, or use other means, such as software tools, to meet the analytical need.

It's also worth noting that there are other ways to speed up MS separations, like working at higher flow, extreme fast programming, and using short, smaller diameter capillary columns. But these do not provide the robustness and loadability of the vacuum GC solution.

Hans-Gerd: LPGC is not unique – it is one of approximately 10 routes towards faster GC. But it is a rather simple technique. In generic terms, I would think it is the preferred method if you have

Meet the LPGC Experts

Steven J Lehotay

Steven J Lehotay is a lead scientist with the USDA Agricultural Research Service at the Eastern Regional Research Center in Wyndmoor, Pennsylvania, USA. Since 1992, he has conducted scientific investigations and method development research involving improvement in the analysis of pesticides, veterinary drugs, and other contaminants in food and environmental samples. Steven is the co-inventor of the "quick, easy, cheap, effective, rugged, and safe" (QuEChERS) sample preparation approach. And he has been awarded with numerous honors, including the AOAC International Harvey W Wiley Award. According to the Stanford c-score metric, he resides among the top 0.19 percent of published analytical chemists.

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simple separations not requiring a high peak capacity and are using MS detection, while sample preparation is not too much of an issue. In such situations, LPGC can increase your sample throughput up to five or ten-fold.

So why haven't more people adopted LPGC?

Hans-Gerd: It's a good question, and we have to be honest here. We clearly thought that all labs would move to faster GC, but nowadays we see that the vast majority of them are still using the classical columns with run times between 30 and 60 minutes. I see two reasons for that. First, I think the need for very fast separation is limited. With a regular run time of say 45 minutes you can easily do 30 samples per day. Many labs will not have that many samples. And we should also not forget that the sample preparation, data interpretation, and paperwork that comes with 30 samples per day can be significant. The GC run itself is usually not the rate-limiting step, and for many the benefits of faster GC are simply not worth the investment and risk.

A second reason for the limited acceptance of fast GC is the strong overpromise in literature and by some manufacturers. With fast GC there is always a price to pay. Narrow-bore columns offer you a faster analysis speed at the expense of a slightly reduced system reliability. LPGC only works for simple separations. Fast temperature programming reduces your separation power a lot. These limitations have not always been communicated honestly.

Jaap: As I've mentioned, some were slow to recognize the value of this technology and I think this has been the biggest limiting step to progress. Even when people (or instrument companies) did recognize the benefits of LPGC, they couldn't see the value in pursuing it commercially. In particular, Varian didn't fully recognize the impact of LPGC having low data acquisition rates.

Steve: Right. Varian made the initial mistake of treating Rapid-MS more as an "introduction device" to their ion trap MS detector, which was not ideal for LPGC due to its slow (250 ms) data acquisition rate. Secondly, the product was introduced before it was fully studied and optimized, leading to narrow marketing and less-than-ideal column dimensions. Another crucial mistake was the over-pricing of the product. Justifiably, the primary goal of a company is to make money – meeting customer needs is only pursued if it serves this primary goal – but if more customers had demanded LPGC, then vendors would have taken more notice. Even so, the 20-year time frame of Jaap's US patent held by Varian and then Agilent certainly put a dampener on commercialization by others until now.

Hans-Gerd also makes good points. Furthermore, LPGC does not work for MS techniques that do not operate with the ion source under vacuum conditions. Also, many volatiles are already analyzed quickly in standard GC, thus LPGC is not going to provide as much gain compared to analyses that currently take 15-60 min. Otherwise, LPGC-MS trades a small degree of separation efficiency for speed, sensitivity, and robustness.

Misaligned incentivization is another problem. For example, nearly all academicians choose to study what rewards and/or interests them the most. The "novelty" of the idea and technique usually motivates them, and they tend to seek applications to suit their preferred tool, not the other way around. Grants, patents, and citations usually drive their choices. Company scientists are similar in that they spend an inordinate amount of their time on niche applications that are difficult for those customers who complain the most loudly. In my view, they should put more focus on improving efficiency and performance of their most profitable applications that are taken for granted. Moreover, the scientific publishers and media tend to highlight "sexy" topics, which are promoted by those scientists on their editorial boards.

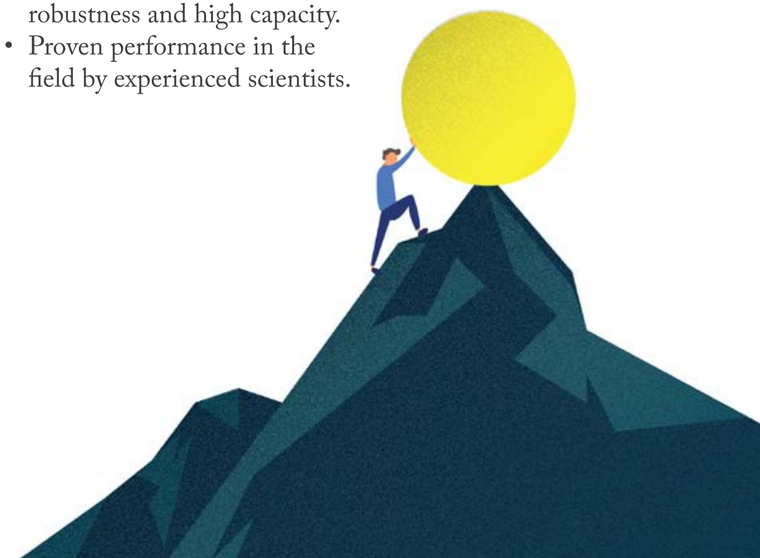
I can give several other reasons more people haven't adopted LPGC. There have been informed criticisms over the years, such as the need for more separation efficiency, analyses of volatiles, or problems with column bleed. But one of my biggest frustrations is to notice dismissiveness, disbelief, and disinformation from those who have never studied or tried LPGC themselves.

LPGC-MS: As it Stands

LPGC is a GC technique that uses an analytical column operating under reduced pressure by using a restriction capillary at the inlet, in combination with a vacuum detector like MS. The technique provides very high linear velocities resulting in short analysis times. It can be used with standard injection techniques and can be used in all MS configurations where there is a vacuum in place.

Aspects of LPGC:

- Fast pesticide screening using GC-MS; typically three times faster than conventional GC-MS.
- Uses a 5 m x 0.18 mm restriction, which also acts as a guard and can be trimmed or replaced.
- A factory coupled column set which has been conditioned and tested; ready for installation.
- An integrated transfer line helps reduce the background noise.
- Thick film 0.53 mm column adds to robustness and high capacity.
- Proven performance in the field by experienced scientists.



What would you like to see for the future of LPGC?

Jaap: In theory, the technique could allow even faster separations depending on the temperature programming speed of the instrument. The 15 m column chosen here could also be replaced for a shorter column – like a 7 m x 0.32 mm or even a 3 m x 0.25 mm column – as long as vacuum conditions inside the separation capillary are created. However, there will of course be other challenges for using such short capillaries, including sample introduction and focusing.

Steve: Do you know what may be even better than LPGC-MS? Fast GC-MS using supersonic molecular beams (SMB) – also known as "Cold-EI." In SMB-MS, the column outlet is not under vacuum, thus LPGC is not possible using that detector. However, column flow rate can be increased to 32 mL/min, for example, to provide rapid, high-quality analyses. I would urge anyone in this field to view the application notes and publications from Aviv Amirav. His long and winding road has also been fraught with multiple bad timings (company consolidations) and human foibles.

Hans-Gerd: A drawback of LPGC is that you need to buy a special "thing"; the restrictor. A big step forward would be LPGC without the need for a restrictor at all. This would require the gas inlet system of the GC to be able to work with sub-ambient pressures while still avoiding the ingress of air via the split exit – but it should be technically feasible.

Also with regards to the future, Steve's work on faster integration methods (summation integration) should be mentioned. The GC run time might be relevant for the total duration of your analysis, but in terms of costs it is not the main contributor. LPGC combined with simpler, fully automated, and more reliable methods for peak integration is an ideal combination.

Steve: Thanks for mentioning the summation function integration. Indeed, you are right to point out some of the drawbacks of LPGC, so I want to summarize how we've been overcoming the current limitations of this technique: i) we have done high-throughput and easy sample prep with QuEChERS (and now QuEChERSER) since 2003; ii) we also have been using analyte protectants since 2003 to improve peak shapes and separations for somewhat polar analytes; iii) for the past decade, we've been increasing selectivity of detection by using MS/MS (for targeted analytes only); and iv) since about 2015, we've used summation integration (for targeted analytes only, too).

You also mentioned the "thing" needed for LPGC – that "thing" is merely an appropriate guard column and union, which are not unusual items. I suppose ferrules for the megabore column is another "thing," but standard columns, liners, septa, ferrules, nuts, and so on are also "things" that by the same logic should preclude anybody from doing any analyses at all! In any case, Restek now sells that "thing" in the same way as any other item, and LPGC has always been available as a custom item.

Hans-Gerd: Excellent remarks Steve! And it's this type of discussion that highlights, I believe, our passion for this often overlooked technique. I know only a few users of LPGC, but I am not aware of anyone who tried it and gave up. The technique works and is reliable and there are certainly more people who could benefit from it.

Jaap: I couldn't agree more.Essentially, LPGC-MS can speed up a lot of conventional MS applications where analysis time is important. It should be of interest to anyone using MS, in my opinion, but the best way to get the word out there is to show the data and let experienced chromatographers speak up.

Steve: As hundreds of people involved in GC analysis can attest, I have discussed LPGC in nearly every encounter with them for more than 20 years! My inclusion of a few slides about LPGC has been a staple in most of my presentations, to the point that some people are sick of hearing about it (and I am definitely sick of talking about it!). I've emailed many gurus of GC over the years about LPGC, and when I noticed research or review articles in which LPGC should have been mentioned, I sometimes emailed key publications about LPGC to the authors to inform them of their oversight.

As a US federal civil servant, I have no business or financial relationships with anyone about my work, and my motivation is to help others improve their chemical analyses and lab operations. I admire Jaap de Zeeuw for inventing the restrictor approach, and I've wished for 20 years that my lab could simply purchase pre-connected LPGC columns with the dimensions of our choosing. Now that this option is available, there is one less excuse for those who haven't tried LPGC-MS.

Hans-Gerd: This has been a trying journey, that's for sure! But we've all come away from it having grown and developed as analytical scientists along the way. For us, the success of LPGC is an excellent example of a cooperation between three parties: academics who develop theoretical concepts, hardware developers that create the tools to put these ideas into practice, and users who re-define the workflows in their laboratory to maximally benefit from the new development. Many successful new methods are the result of such three-party interactions.

Hans-Gerd Janssen is Science Leader of Analytical Chemistry at Unilever Research Vlaardingen, and Professor of Biomacromolecular Separations at the van't Hoff Institute for Molecular Sciences at the University of Amsterdam, the Netherlands.

Jaap de Zeeuw is Int GC Specialist at Restek Corporation

Steven Lehotay is a Lead Scientist with the USDA Agricultural Research Service, Eastern Regional Research Center in Wyndmoor, Pennsylvania, USA.

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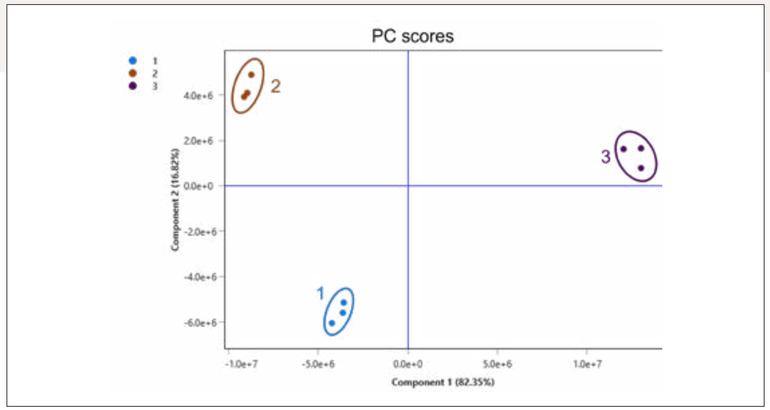
APPLICATION NOTE

An Analytical Workflow for Pumpernickel Bread Varieties

GCxGC-TOFMS and ChromaTOF® Tile Software combine for an efficient, supervised statistical analysis



Principal Component Analysis (PCA) scores plot displaying clustering of the Pumpernickel bread extracts according to their aroma-type and recipe.

Subtle variations in a recipe can have vastly different results in the final product. This can be especially true for baked goods, where a different oven may use a different heat cycle, changing the final flavor profile, or the origin of ingredients might sway the results. Recipes and processes are continuously developed to meet consumer preferences, adjust to supply chain challenges, and to increase market competitivity in this enormous global industry. Therefore, these processes are subject to much analytical scrutiny. Anything one producer can do to give themselves a leg up on the competition may provide a huge advantage for what may be a subtle change.

Pumpernickel bread comes with a complex and challenging matrix. While 1D GC-MS is a typical first step, for a complex matrix, it can be more efficient to jump straight to GCxGC-TOFMS analysis. The added dimension improves separation as analytes that coelute in the first dimension can be easily differentiated when run through a column of differing polarity.

GCxGC-TOFMS works great for one sample, but it provides such rich and detailed chromatographic data that the sheer volume of information may become a challenge to interpret when more than a few samples are run. Comparing these sets of data aren't as easy as layering the chromatograms on top of each other and playing "spot the difference." Small variations across chromatograms can be problematic to manually align, making it impossible for basic statistical analysis to produce any sort of coherent automated information.

ChromaTOF Tile software, however, is far more than a basic statistical analysis package. Seamlessly integrated into ChromaTOF, ChromaTOF Tile partitions data into regions (tiles), creates Fisher-Tile ratio calculations for each set of data, and compares those values. This enables the software to accommodate for subtle data variations efficiently and effectively – automatically highlighting truly statistically significant finds to the top of a list for your scientists to study. Even when it comes to a sample as challenging as pumpernickel bread, ChromaTOF Tile, combined with GCxGC-TOFMS data, can cut hours, days, weeks, and even months off your analysis times.

SEE WHAT YOU'VE BEEN MISSING WITH OUR LATEST PUMPERNICKEL BREAD APPLICATION NOTE TODAY.

FEATURE

The Environmental Chromatographer

We chat with Frank L. Dorman, Resident Scholar at Dartmouth College, former Associate Professor at Penn State, and Senior Principal Environmental Market Manager at Waters Corporation, who remains excited (and concerned) about the impact of environmental pollution on human health – after more than three decades working with gas chromatography-mass spectrometry

How did you get into analytical science – especially the environmental side of things?

I was brought up in Pennsylvania – about 45 minutes to the southeast of Pittsburgh. I was right in the middle of the decline of the steel mills; the pollution from them – and the impact on the local area – was something we were all very aware of. Mostly, it was the financial impact that everyone worried about, but I can still picture the areas of defoliation that were downstream from the mills. Nothing grew there and even as a kid you had to wonder what that meant for human health (though we didn't use those words as kids).

I went through school always interested in two areas: music and science (probably in that order). I almost went to music school but decided to pursue a college education and focus on science, which eventually became a focus on analytical chemistry. I graduated from Juniata College in 1987 and went on to the University of Vermont to get my PhD in in analytical chemistry in 1992.

Following my PhD, I became a senior chemist with a large network environmental testing laboratory that allowed me to get a ton of experience in a wide variety of areas, including gas chromatography-mass spectrometry (GC-MS) and sample preparation for organics analysis. That was my entrance into chromatography and MS – and I'm still here more than 30 years later!

I left the commercial environmental world to take a position with a chromatography consumables manufacturer, where I eventually became the Director of Technical Development (basically, R&D). In this capacity, I was able to bring back my interests in physical chemistry and apply those to the design and manufacture of a number of novel GC column stationary phases – working alongside one of my oldest collaborators and friends, Paul D. Schettler. While I was with Restek, I also began a research faculty appointment at Juniata College and began to support and mentor undergraduate research students. There, I collaborated with Jack Cochran, who became a great friend; he has also contributed immensely to research that I have been involved with over the years.

You then moved fully into (and then out of) academia…

Yes. After 14 years I finally decided to take the jump into full-time academia, taking a position at Penn State University as an Associate Professor. There, I established a research group that used various separation science tools in environmental forensics, forensic chemistry, and analytical chemistry. I was truly honored to have a number of fantastic graduate students; it was a very enjoyable experience. In my 10 years at Penn State, I believe that my students made a significant impact to the body of scientific knowledge – I am extremely proud of all of them. A PI couldn't hope for more!

Most recently, I took a position back in industry with Waters Corporation as Senior Manager for Global Environment Marketing. In addition, I have an academic appointment at Dartmouth College as Resident Scholar, so I am still engaged in teaching and expect that I may have opportunities to help mentor research students – which has been some of the most fulfilling work I have done over my career.

Tell me about your Scientific Achievement Award from GC×GC?

This award was presented virtually at the 2021 GC×GC Symposium. Unfortunately, the pandemic didn't allow us to meet face-to-face. I believe it was awarded for a career of research in multidimensional GC×GC and I would have a difficult time highlighting a single paper. Perhaps I should take this opportunity to thank a few of my greatest collaborators – people who have worked alongside me in this exciting field for many years and without whose help many of our efforts would have been much more difficult, if not impossible. I've already mentioned Jack Cochran, but I should add Eric Reiner and Jean-Francois (Jef) Focant to this list. The four of us remain good friends to this day and we've shared a number of great times that have resulted in some excellent science – and great stories!

I also need to point out that much of my work would never have been possible without a huge amount of support and collaboration with LECO Corporation. Specifically, Mark Merrick and Michael Mason have both been enormously helpful – and I'm happy to call them friends as well. Lastly, without the vision and support of Donald Patterson Jr and Jean-Marie (John) Dimandja I believe my research group's work would have been more difficult and, in fact, the field of GC×GC would not be where it is today.

Many thanks to all!

In terms of your research to today, what "gets you out of bed in the morning?"

Besides coffee and ski racing? At least with regards to science, I continue to be concerned and excited to learn more about how we impact human disease through exposure to the myriad of compounds in just about everything. It is clear that, though we benefit from the use of things like pesticides, for example, they may also have a deleterious effect on our health. Understanding this, however, is exceptionally challenging. It involves a very wide range of skills that demand high-quality collaborations – no single person or group can effectively research this area on their own. And I still get very excited about a new technique or finding that may allow us to further understand our complex chemical world in the hopes of making a positive impact to our health and our planet.

What is your view on the value of physical meetings for the field?

I believe that we have come to accept virtual meetings (and they do have some benefits), but there is still nothing like in-person meetings. In-person symposia are more effective when it comes to the social interactions that play such a critical role in the establishment of a scientific network for an individual. We accomplish so much more when we work as a team. That said, I already have my wonderful network of collaborators, so we can still get on calls to get caught up, but for people in the early stages of their career, I can't imagine how they will cope – and that will surely have a negative impact on our field.

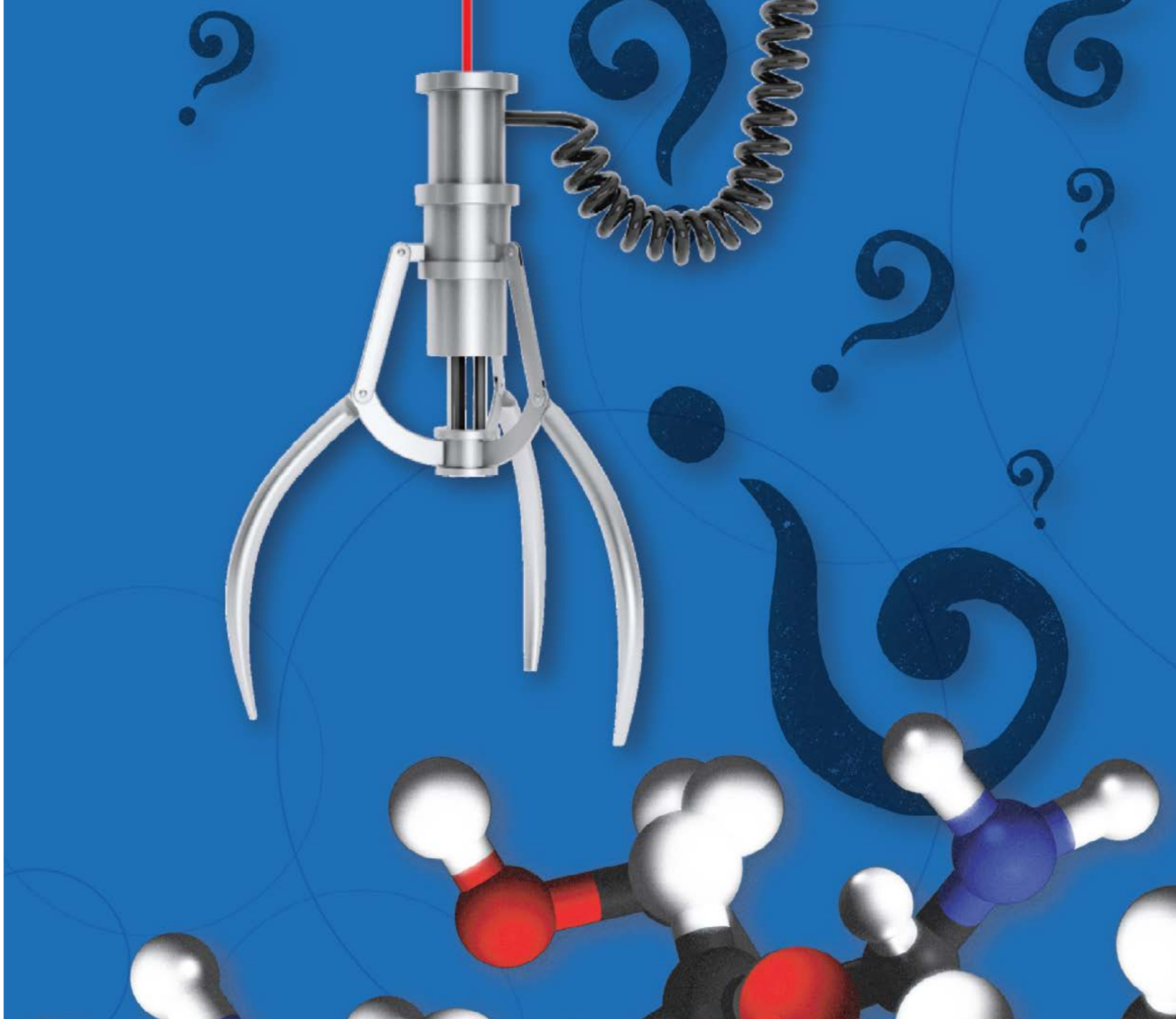
FEATURE

The Ultimate Untargeted Technique

Where does the hyphenation of GC×GC and high-resolution MS fit in the quest for enhanced resolution in (breath)omics research?

The rise of omics has been a hot topic in our group for the past few years – in part because our own expertise aligns somewhat with the needs of these fields. Metabolomics is then particularly challenging for the separation science community, demanding the application of high-end iterations of various techniques, including LC, GC, MS, and NMR. In fact, when it comes to metabolomics, most analytical tools have a "seat at the technique table" – after all, multimodality is the only way to make sense of such high sample complexity.

Multidimensional chromatography holds one of those seats, and often comes up in conversations on how separation power should be best enhanced. Such discussions essentially center on a single question: would it ultimately be better to have analytical separation based exclusively on an ultra-high-resolution mass spectrometer or through a combination of high-resolution techniques with orthogonal dimensions (chromatographic and mass spectrometric)?



Author Delphine Zanella

Author Pierre-Hugues Stefanuto

Author Jean-François (Jeff) Focant

There is likely no definitive answer to this question, but we hope our works demonstrate the use of comprehensive two-dimensional GC (GC×GC) coupled with high-resolution MS (HRMS) as one compelling option. By combining these techniques – and thus exploiting several levels of orthogonality – we have been able to improve both the versatility and the robustness of the unknown compound identification process – particularly in the young field of breathomics, which we'll talk more about later.

Pieces of the puzzle

On the chromatographic side, linear retention indices (LRIs) provide a first identification metric for unknown compound that can be compared with true-standard values and commercial libraries (for example, NIST, Wiley). It is also useful to estimate the carbon number of unknown compounds; in the context of GC×GC, the structured elution pattern provides information regarding the carbon number – and it also indicates the polarity and even the chemical class of the eluting unknowns.

Next comes the ionization method – the physico-chemical transformation link between chromatographic separation and MS analyses. In the context of GC, electron ionization (EI) offers a key advantage over LC-based approaches, which suffer from time-consuming peak annotation (1) (2). In fact, EI provides a highly reproducible fragmentation pattern regardless of the analytical conditions or instrument (3), which allows us to compare fragmentograms with reference libraries to provide MS-based identification. At the end of the process, MS analyzers add the final touch of the identification step with an efficiency that is directly proportional to their mass resolution and accuracy – two metrics that are constantly increasing for all types of MS analyzers (and independent from the chromatographic separation side).

GC×GC-HRTOFMS has become increasingly available for routine analysis over the last decade. This trend began when it was used to completely characterize single samples (4), but as data processing methodology for low-resolution data evolved and was applied to HR data, GC×GC-HRTOFMS soon became useful for studying larger samples (5). Nevertheless, untargeted metabolomics is a complex playground; sample preparation and optimization, QC elaboration, data processing, and so on, all still represent real challenges. Building on this early work, GC×GC-HRTOFMS has now been extensively challenged by metabolomics with various levels of success (6). In our group, we have been investigating different applications.

Looking to serum

To develop and validate a reliable analytical method, we have focused on the analysis of derivatized serum samples. This matrix has been

investigated thoroughly using standard GC; this work, conducted by pioneers like the Fiehn Lab, provides a strong basis on which future research can be built.

Our first step was the optimization and validation of analytical conditions using a NIST standard reference material for human plasma (1950) (7) (8). We demonstrated the applicability of our method through a proof-of-concept study that identified 33 serum metabolites specific to Crohn's disease. Orthogonal identification capacities allowed us to annotate half of these with Metabolomics Standards Initiative level two confidence. Now we're taking advantage of a sensitive, high-speed MS analyzer to conduct this research with minimal sample volume and preparation, providing an exciting focus for the coming years.

Our larger aim is to develop a multiomics screening platform for this universal matrix. Though small molecules can be characterized by GC(×GC), complementary information that completes our knowledge of these samples will come from LC(×LC)-MS and MS-only screening. Thus, combined approaches are needed to lift the veil of relevant metabolic pathways.

Research is in the air

Another area for GC×GC-HRTOFMS application is volatilomics, which describes the metabolomics-type screening of volatile organic compounds in complex matrices. The best way to characterize small volatile molecules in normal conditions is to transfer them directly into the analytical instrument, avoiding extensive sample preparation. In this field, however, the constant development of trapping devices (solid-phase microextraction fibers, thermal desorption tubes, and so on) allows for the robust sampling of volatile molecules. Yet, the validation of routine analytical strategies for volatilomics remains challenging. This is mostly because of a lack of reference materials and difficulties performing interlaboratory testing.

Our lab has worked on various untargeted volatilomics applications – from food to plants – but the medical field has been our main target over the last five years or so. During that time, we have worked on the development of a complete analytical workflow for exhaled breath characterization (9) (10).

Breath research is a growing and challenging field for analytical scientists. From reliable sampling to robust processing, all involved steps need to be carefully controlled. The strategies employed must also be adapted to context-dependent needs. GC×GC-HRTOFMS has been our "go to" instrument for this type of research. For on-site support and diagnosis, direct MS methods (for example, selected-ion flow-tube MS and proton transfer reaction-MS) seem to be the fastest and most-adapted tools.

Based on a number of studies on lung cancer detection and inflammation phenotyping, we've conducted the first large-scale study on breath, combining targeted and untargeted screening (11). In vitro models then allowed us to determine the cellular origins of these volatile molecules (12). Combining information from volatile molecules identified by such methods and larger molecules in the liquid phase is necessary to complete multiomics visualizations – underscoring the power of complementarity between techniques.

With the increasing use of GC×GC-HRTOFMS in untargeted metabolomics, the future looks exciting (6) (13). Still, multiple challenges should be tackled to make GC×GC-HRTOFMS a truly recognized contributor to large-scale untargeted screening. The biggest challenges remain at the level of the study design and data processing workflow – it is paramount that the robustness and accuracy of every individual measurement is consistent throughout the entire batch. This will only be achieved with a better definition of QC procedures (especially for volatile samples), a better understanding of chemometric tools, and the development of integrated software solutions to manage the different steps from injection to processing output. But none of these challenges are unique to the technique; therefore, strong collaboration between different fields of analysis will be required to successfully overcome them.

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Delphine Zanella, Organic and Biological Analytical Chemistry Laboratory, MOLSYS Research Unit, Liège University, Belgium

Jean-François (Jef) Focant leads the organic and biological analytical chemistry group of the mass spectrometry laboratory at the University of Liège in Belgium, where his research interests include the development of new strategies in separation science and the implementation of emerging strategies for human biomonitoring and food control. "I've been active in the field of dioxin analyses for the last 15 years and chaired the international Dioxin 2011 symposium in Brussels," says Jef. Well known as a dioxin expert, he is also active in characterization of complex mixtures of volatile organic compounds (VOCs) for medical and forensic applications. "Working on the hyphenation of state-of-the-art analytical techniques to solve practical analytical issues is what I really enjoy doing," he says.

REFERENCE AVAILABLE ONLINE

FEATURE

My GC×GC Story

Join me on a comprehensive trip down a two-dimensional memory lane – and reflect on the legacy bequeathed by John Phillips

Philip Marriott

John B. Phillips – in collaboration with Zaiyou Liu – is recognized as the inventor and "father" of comprehensive two-dimensional gas chromatography (GC×GC). His untimely passing in 1999 meant that he never witnessed GC×GC flourish into a new force in ultra-high-resolution GC analysis. Though not widely published, his research spanned multiplex GC, thermal desorption and on-column modulation, and fast GC with thermal modulation – and can be seen as a precursor to what was to come. His spirit of innovation was evidently invested in his former students, such as Janusz Pawliszyn – the inventor of solid-phase microextraction – who studied on-column photochemistry in glass GC columns with John.

I am not sure how many chromatographers got their inspiration to commence GC×GC from hearing John Phillips "wax lyrical" and extol the virtues of this new operating mode he had started working on – but I did. My student Russell Kinghorn and I had been researching the benefits of a longitudinal modulation cryogenic system (LMCS) – an idea I had at the ISCC meeting in Riva Del Garda in May 1994 while listening to Hans Gerd Janssen discuss large volume injection. (But that is another story.) The essence of the LMCS is a cryogenic region encapsulated in a small "shuttle" device that oscillates back-and-forth around a capillary column. The idea was that it would/should allow trapping and rapid re-mobilization of a migrating chromatographic band – a theory we were able to demonstrate.

"Though certainly not lacking in imagination, I doubt John [Philips] would have guessed – or dared dream – of the legacy that he bequeathed to the GC community."

John had been invited to a chromatography meeting in Sydney, and I was organizing a satellite meeting in Melbourne – the Victorian Separation Science Symposium (1997). This was a good chance to snaffle the speakers who were visiting Sydney. John was eloquent, and very upbeat about this new GC×GC technique. And why wouldn't he be?! Today – perfectly vindicated – GC×GC has spawned a whole new area of advanced capability in GC analysis. The technique was critically dependent on the process of transferring narrow "cuts" from a first (1D) to a second (2D) column – and to do so with an incredible efficiency, delivering an extremely sharp band to the 2D column. Russell and I must have had the same idea, at the same time; "Surely our LMCS could work as an effective modulator for GC×GC" – we whispered as John spoke. So we dropped everything, and focused on developing the concept of a cryogenic modulator for GC×GC. The rest, as they say, is history – our cryogenic process has proved to be a great enabling modulation mode for GC×GC.

But at that time, John reminded me that we had met before. At Pacifichem in Hawaii, in 1985, when I was at the National University of Singapore. We met at my poster on chemical interconversion processes in GC – research that we are still doing today, but now using GC×GC. A story within a story!

Cryogenic devices and GC×GC modulation

John lived long enough to see his vision taken up by a select group of researchers, but their enthusiasm did not translate into major chromatography companies running with the idea. Tools for doing GC×GC were largely in-house devices or the sweeper interface that Zoex championed. Our cryogenic concept apparently spawned a similar device – the dual jet cryo-system at the heart of the LECO GC×GC commercial system. And with the hardware sorted out, LECO was then charged with developing software control and data presentation/reduction for GC×GC. So at last, GC researchers and industrial users could access a package that offered the full suite of hardware and software required for many research and industrial applications.

How did LECO commence their journey in GC×GC? It is hard to know the inner workings and discussions within a commercial entity, but LECO had already commercialized fast GC-TOFMS technology. And I recall that at the Wintergreen ISCC (1997) meeting there was some excitement about TOFMS for very high throughput GC-MS analysis – and some of us realized that such capability was almost perfectly suited to the acquisition rate demanded of GC×GC. Most users had to be satisfied with FID and other GC detectors – not all correctly engineered for peaks 0.1 s wide. We knew samples were much more complex than a 1D GC analysis suggested – we could see all those extra peaks staring right at us in the GC×GC result! But that also posed a universal and highly unsatisfactory problem: we couldn't identify those same peaks. All a sceptical observer had to ask was, "What are all those peaks – are they real?" And given that our answer was, "We don't actually know," it was easy to dismiss the value of GC×GC. MS had to be a priority.

Putting TOFMS to work for GC×GC

A couple of years later at the Park City ISCC meeting (1999), a few presentations really put GC×GC in the spotlight – but where was MS? A few of us – René Vreuls, Jan Beens, and I – had a serious discussion with Rick Parry (at that time LECO's Separation Science Product Manager) to beseech LECO to move into GC×GC, based on using their TOFMS technology. We knew such technology would help GC×GC users step up to the next level.

To be honest, I'm not sure if Rick took this idea to LECO or if the company was already deep in discussions regarding GC×GC technology; perhaps all we did was confirm our commitment to GC×GC with TOFMS, giving "extra ammo" for Rick to transmit to LECO. Irrespective, early researchers adapted TOFMS to various modulators as bespoke hyphenated systems; later, LECO adopted GC×GC with TOFMS – much to the delight of our close-knit community.

So, John Phillips' earlier demonstration of separation of complex petrochemical and atmospherics samples truly was a beacon illuminating the path towards super-high resolution GC×GC.

Then, Don Patterson's very compelling study of contaminants in human adipose tissue was presented at Wintergreen ISCC in 1997 for trace dioxins following the factory explosion at Seveso. He required the absolute best separation and sensitivity of analysis, and this allowed translation to sampling less of the adipose tissue that was needed to

provide a positive screen for exposure. If I recall, he said that it was easier to convince someone to part with a 1 g fat sample than to request upwards of 20 g to achieve the necessary detection limits…

Fast forward – GC×GC today

For many in the GC community, simply seeing a 2D chromatogram plot is sufficient to clearly demonstrate the capabilities of GC×GC – enough to ask, "How do I get a piece of this action?!" And the fact that GC×GC is based firmly on principles of GC means that it can be easily understood in terms of operation and design. There is no "jiggery pokery" required to make it work; apply the technique correctly and it will reward the analyst with both separation and sensitivity.

However, tools to correctly report the hundreds of peaks in our analyses both reliably and precisely are crucial. Getting baselines correct, assigning modulated peaks of a given component to that compound, and being able to do this over a series of replicates or a long time-series analytical study, requires the software engineer to ensure the tools process data correctly. But I would say that the final GC×GC result is clearly better than the significant uncertainty that accompanies a poorly resolved 1D GC result.

There is no reason why every sample that is analysed by 1D GC cannot or should not be applied to GC×GC methodology. All the information available to a 1D GC analysis is still available in GC×GC, but the latter will almost assuredly provide information or details that were not available or evident using a 1D GC method! In other words, the risk/reward equation firmly favors the reward side.

The killer application?

Many analysts are asked – with respect to a new or alternative technique – "What are the killer applications?" This question was especially pertinent for capillary electrophoresis, which was promoted as an alternative to (or at least could be applied to) many applications suited to HPLC. But I don't think there was one killer application that demanded the community to move from packed to capillary GC analysis; instead, it just happened as a natural progression in technical capability. Put simply, capillary GC offered much better resolution in a similar time. And so it is with GC×GC. Although the nuances of the technique and the extent of training, familiarization, and method development are acknowledged, better sample characterization is its own reward.

I'd say every lab dealing with volatiles needs GC×GC at the heart of its capabilities – as prior screening of samples or a process using GC×GC allows the analyst to delegate samples to 1D GC, GC-MS, and so on, as the specific analysis demands.

In fact, GC×GC offers a unique generic capability that simply has no analogy in 1D GC. And that's the opportunity to use clustering of compounds in the 2D separation space to simplify data processing, sample-to-sample comparisons, and process interpretation for sample analysis. This might be a "killer capability," rather than a single application. With the ability to essentially "see" all the important compounds in most samples – especially for non-target applications – the analyst is free to apply whatever interpretation they require to their data, "without let or hindrance."

Thus, GC×GC has spread its wings. Though certainly not lacking in imagination, I doubt John would have guessed – or dared dream – of the legacy that he bequeathed to the GC community.

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SITTING DOWN WITH

Separation Crazy; Separation Mad

Sitting Down With… Tony Edge, Site Director (Production & R&D), Avantor Sciences, UK

Did you always want to be a scientist?

The blunt answer is no. I genuinely had aspirations of playing for Manchester United – holding the FA cup aloft! But those dreams were dashed fairly early on when I realized that I didn't quite have the talent to play professionally. Fortunately, science took over by my teens. I wanted to be a physicist originally – all of my university applications were for physics degrees. That didn't quite materialize and I ended up developing a passion for chemistry, especially the physical underpinnings of the field.

Initially, I was looking at reaction kinetics and fluid dynamics, which led me to chromatography. And I found the perfect combination; if you look at some of the underlying equations that govern chromatography, it's all fluid dynamics; and if you consider chromatographic separations, it's all reaction kinetics. Since then, I've been separation science mad.

You've had a wide range of roles throughout your career. Any major lessons learned?

There are many lessons I've learned from a technical perspective. But one key overarching lesson is: Don't be afraid to try stuff! I remember early in my career, my PhD supervisor asked me for my advice on something he was a world-leading expert on. I remember thinking, you've written hundreds of books on this and you're asking me? But it taught me that everyone's opinion should be respected. Often we don't put our hands up because we're too frightened, but a wide range of perspectives challenges dogma. So put your hand up, try something out, you might love it! Most people reflecting on their careers only regret the things they didn't try.

What's the biggest development in chromatography over the course of your career?

There's been a myriad of developments given the length of my career! One of the key ones has to be the introduction of ultra-performance LC and the sub-2 micron particle. It got everyone thinking about what they could do with this kind of sensitivity – and it also inspired the launch of superficially porous materials. Too often we become fixed in our ways because things work relatively well, so why bother? Sometimes it takes a technological leap forward to give everyone a wakeup call. Sub-2 micron was a fulcrum point for the field of separation science – and it is still having ramifications today.

"Instead of running with a bit of kit that's a meter high, weighs 500 kg and costs hundreds of dollars per sample, we could have a device that sits on your wrist and monitors your health day to day. We need to keep moving chromatography forward."

What about the future of chromatography?

I often hear people say things like, "Chromatography is an older, more robust technology." Though I don't disagree, there are a number of exciting applications on the horizon. One thing COVID-19 has taught us is that mass testing at a scale of billions of tests every week is something that the general populace will do. And if we look at the technology involved, that's not so far removed from a chromatography column. We already have smart watches that can tell our heart rate, temperature, or glucose levels. What information would we glean if separation science was involved?

From a technical perspective, multidimensional chromatography and the work coming out of the University of Amsterdam is incredibly exciting. The ability to create 3D printed columns is something I've always been fascinated by, and I can see that coming to fruition in the very near future.

Finally, in terms of chemistry, if we look at the space industry, they have had to develop chemistries that are stable in very extreme environments. Could we apply some of those technologies to the field of chromatography? The fact that we can now send a GC-MS to the planet Mars suggests that chromatography has got an important role in the future – perhaps discovering life on distant planets!

Is there a lack of appreciation, especially among students, of the importance of chromatography?

Absolutely. I think there are two challenges. First, not everybody knows what chromatography is. Second, even if they do the blotting paper experiment at high school and gain some understanding, they never find out how powerful chromatography is.

And because the technology is more robust, you don't need to know how it works to use the machine – you just need to hit the big green button. And that's a shame because we need gifted people who understand the fundamentals to develop next-generation technologies that we'll need to improve our health, ensure our environment is stable, or make sure the food that we eat is healthy and safe. There's so much more we can do with chromatography in these areas so it is frustrating when people think of it as a "green button" technology.

Have we accepted mediocrity?

Some have, yes. There is an attitude of "that'll do," which I strongly reject. Instead of running with a bit of kit that's a meter high, weighs 500 kg and costs hundreds of dollars per sample, we could have a device that sits on your wrist and monitors your health day to day. We need to keep moving chromatography forward.

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SPOTLIGHT ON...

Technology

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