Enhancing Fire Scene Investigations Through New Technologies

By John David DeHaan, Ph.D.

Abstract: The application and limitations of field-portable Gas Chromatography/Mass Spectrometry (GC/MS) to fire investigations was the focus of this project. Today's fieldportable GC/MS systems were found to provide lab-quality data for volatile hydrocarbons but the interpretation of that data proved challenging for field operators. On-line access to lab experts is essential. Scene investigators felt that data generated at the fire scene is useful, especially for public agencies who often must wait months before receiving lab results. Scene sampling using SPME has proven problematic due to the over-saturation of the sensitive SPME fibers and their rapid loss of adsorbed compounds. Sampling at ambient temperatures limits the range of identifiable. products. Evidence sampling is enhanced with the use of sensitive PIDs (photoionization detectors). as a supplement to canine searches.

This project, from its outset in 2013, has been to assess the feasibility of employing GC/MS (gas chromatography/mass spectrometry) at fire scenes to identify possible accelerants with sufficient accuracy to allow the investigator to further the investigation (search warrants, interviews, etc.) based on reliable lab results. This study involved the use of several different field-portable GC/MS systems designed for HazMat/WMD responses, some of which have been reported on previously. The project phase reported here had two objectives. The first was to analyze and compare GC/MS data from both field and bench GC/MS analyses of debris from live fire tests and from 15-30 fire scenes where ignitable liquids were suspected. In concert with canine searches and advanced technology hydrocarbon detectors (sniffers), evidentiary samples were taken, field-tested, and sent to an accredited fire debris lab. Second, once the quality of data was assured, investigators evaluated the impact on decision making and fire investigation outcomes from obtaining reliable GC/MS data at the fire scene. These evaluations were not intended to replace canines, “sniffers”, or accredited lab analysis for judicial processes, but to improve the information investigators could use while still at the scene.

Introduction

Fire investigators rely on detection and lab analysis of samples (typically burned debris) to reveal the presence and identity of ignitable liquids as evidence of the incendiary nature of the fire. For many years fire investigators relied on their own sense of smell to detect possible accelerants in fire debris. With the realization of the health hazards involved, investigators used a variety of hydrocarbon detectors. Combustible Gas Detectors (CGD) using a sampling pump and a heated-wire sensor were very popular and worked well but could be overwhelmed if exposed to very high concentrations of flammable vapors and had numerous interferences. Solid-state detectors offer fail-safe use but have no pumps and must rely on vapors drifting into contact with the sensor and then dissipating, resulting in slow, stop-and-start searching.

The ppbRAE 3000® detector used in these tests is a photoionization detector (PID) with a continuous pump drawing air through the sensor and back out again. (See Figure 1). It will be described in full in a later section. The sensitivity of the ppbRAE 3000® used here can measure hydrocarbons down to a few parts per billion (ppb).[1] This is contrasted with the lower detection limit for other “sniffers” on the order of a few parts per million (ppm), or the normal human nose with a threshold for gasoline of around 1 ppm. [2] For reference, the estimated threshold for trained, certified accelerant detection canines is on the order of 20 ppb (parts per billion). [Unpublished data from tests at fireK9.org testing February 2019 by authors.] With its small sample volume and fast pump, the ppbRAE® clears quickly, making rapid searches of a room possible.

Canine detection teams have been in use by fire investigators since they were introduced in the late 1980’s. They have tremendous sensitivity, coupled with great speed in

Figure 1. Rae Systems ppbRAE 3000® Portable PID. (Photo credit Rae Systems®).

searching many environments. If properly trained, they have very high rates of accuracy for the detection of residues of ignitable liquids at even badly damaged fire scenes. While 100% accuracy cannot be claimed, their accuracy is high enough to provide a high degree of probability for the investigator to move forward with his/her investigation and to recover samples from the indicated place for lab confirmation. However high their discrimination, canines cannot confirm a specific product and the investigator should not trust a canine alert as proof of the presence of an ignitable liquid.

Once detected, the volatiles must be captured and analyzed by a qualified forensic lab using GC/MS for court use. There, the volatiles must be extracted from the charred wood, soil, and other solids. Once accomplished by steam distillation or solvent extraction, the recoveries were not very high as both methods involved physical collection and evaporative losses during processing. Direct headspace sampling involved typically 1ml of headspace air drawn from the heated container with a syringe and injected directly into the GC. This was possible as GC's became more sensitive. This method had a limited sensitivity because heavier petroleum products such as kerosene or diesel may not produce enough vapors to be detectable at room temperatures, thus requiring heating of the sample can before headspace sampling.

In the 1970's, more sensitive isolation techniques were developed using activated carbon (charcoal) on or in various devices (steel wire or needles, glass marbles, pipettes, polymer strips, or tea bags) inserted into the evidence containers. The trapped volatiles adsorbed onto the charcoal were then extracted with a very small amount of solvent which was then injected into the GC. This proved to be a very sensitive and versatile extraction method, with minimal risk of contamination or loss of volatile evidence. (It is described in ASTM E1412-19) [3]

Some polymers showed an affinity for attracting and adsorbing volatile traces. Termed Solid-Phase Microextraction (SPME) sampling, the technique was found suitable for testing for ignitable liquid vapors. The polymer fibers were exposed to vapors which adhered to the fiber and could then be placed directly into the injection port of the GC for no-loss recoveries, as the adsorbed traces were driven off by the heat inside the GC. (It is described in ASTM E2154) [4]

This method is extremely sensitive and non-invasive, requiring no contact or handling of the substrate, but the small surfaces of the SPME fiber are easily saturated. [5] This would not be a problem for single-compound unknowns, but oversaturation of SPME fibers (and charcoal) results in displacement of light volatiles by heavier ones, and alkanes (aliphatics) by aromatics. This process distorts the peak profile of a complex mixture by which most petroleum products are characterized. In forensic practice, the sampling process would be repeated with shorter exposure times and injections until an undistorted profile is achieved. In field collections, the oversaturation can be minimized by adjusting the fiber exposure time based on measuring the concentration of vapors using a sensitive monitor such as the ppbRAE 3000® PID prior to sampling. SPME was the procedure used in collection of the field samples in all but the final stages of this study of identification of volatiles using field portable GC/MS. In the final stage of testing here, samples were taken using a direct sampling of vapors (Air Confirm©) without SPME.

Materials and Methods

A reproducible testing protocol at fire scenes developed in earlier testing and aligned with industry standards was implemented by investigators from a private fire investigation firm in the last phase of project tests. [6,7] The protocol started with an area of concern whereby a canine "alert" was followed-up with a PID confirmation utilizing the "headspace cup method" (employing a clean paper cup inverted over the suspected area to create a concentrated modified headspace (See Figure 2.) Evidentiary samples were taken in that location and placed into an evidence can. Prior to sending collected samples to the fire debris lab, both PID and GC/MS were used on the headspace of each can to gather additional data.

Figure 2. The "headspace cup method" utilizing a paper cup to create a modified head space to increase the concentration of ignitable liquid vapors using the PID. Courtesy of Dan DeMille, Utah Valley University, Provo UT

The Griffin G-510® GC/MS is a field-portable linear quadrupole-based mass spectrometer that provides a measurement range of 18 to 510 atomic mass units (AMU), and its gas chromatograph is programmable over a 40°C to 300°C temperature range. (See Figure 3).

Figure 3. Photo of field portable Griffin G510® GC/MS. (Photo courtesy of FLIR Detection, Inc.).

It has an air sample device for collecting air bearing dilute vapors of interest, as well as a vapor sampling probe for performing rapid mass-spectrometric-only analyses of chemical vapors. The gas chromatograph operates on helium carrier gas supplied by a removable internal gas cylinder. Operating power can be supplied by external 120-to-240-volt Alternating Current (AC) electrical sources or by two internal rechargeable lithium ion batteries. Starting with one fully charged battery, the operating time is approximately two hours in survey mode and one hour in full GC/MS mode. Operating times double when starting with two fully charged batteries. [8]

A Rae Systems® (Sunnyvale CA,) Photo Ionization Detector (PID) ppbRAE 3000® (See Figure 1) was used

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in each of these tests because of its sensitivity and selectivity for volatile hydrocarbon compounds. (Its selection was based on the experience of one of the authors using it in HazMat training.) The novel sensor element consists of a small quartz optical cell with an ultraviolet (UV) light source. The energy (wavelength) of the light is such that only compounds with a suitable ionization energy will cause the sensor to react.[1] In fire investigation, it will measure the concentration of volatile petroleum products and a limited number of chemically related vapors over a concentration range from parts per thousand to ppb and only minimally to methanol. The ppbRAE 3000® uses a 10.6 Electron Volt (eV) photoionization source, which means it will react to a wide range of flammable liquid vapors while ignoring common compounds such as water vapor, CO, and methane which are common interferences with other "sniffers" (Confirmed by unpublished lab tests conducted by the lead author in October 2018.) Because the "inhaled" sample is not destroyed, it can be pumped directly into an appropriate sample bag attached to the exhaust port for later lab identification.

History of Project

The testing of technologies to enhance fire investigations by these authors has been on-going since 2013 with five separate stages and many milestones (See Table 1). It was argued that fire investigators could be more effective when armed with GC/MS data that could be useful in evaluating areas of concern, interviewing of witnesses and potential suspects, or providing defensible probable cause while at the scene. In addition, identification data from transitory evidence that may be lost due to weather, faulty sampling techniques, or other causes could be captured at the scene. It is important to note that the data produced at the scene was not intended to replace the need for lab results from an accredited fire debris lab. In Stage 1 (summer 2013 to summer of 2014), research designed to test the field application of GC/MS teamed with SPME fiber sampling to fire/arson investigation was completed and published in a peer-reviewed publication. [6]

In Stage 2, a state fire marshal's office investigator went through three days of training and was provided with the equipment needed (GC/MS by Smiths Detection® and PID by Rae Systems® (Honeywell®)). Issues primarily with GC/MS equipment reliability, manufacturer and organizational support, and internal cultural hurdles within the investigator's organization resulted in limited impact from the effort. During that time, we participated in canine certification processes providing evidence of the sensitivity of the canine related to the ability to provide identification of the ignitable liquids with GC/MS data. [9]

In Stages 3 and 4, a certified private fire investigation firm offered to collect GC/MS data at real fire scenes. In October of 2017, a new sponsor (Griffin®G510 GC/MS, by FLIR®) was found.

Table 1: Stages of Field Portable GC/MS Research 2013-2020

Stage 1: June 2013-August 2014, (GUARDion GC/MS by Smiths Detection, SPME sampling).	
	Bench/scale tests (Texas and California), Room fires to flashover (SLOFIST, UVU, Merced, Napa). Presentations: ISFI (University of Maryland) [5]
Stage 2: August 2014-December 2016 (GUARDion GC/MS by Perkin-Elmer/Smiths Detection, SPME sampling)	
	The application and limitations of field-portable GC/MS to fire scene investigations with integration with canine teams was the focus of this project phase. State fire marshal investigator/canine handler. Scene examinations (2015-2016)
	Canine testing at canine conferences: November 2014 November 2015, and
	CAC: October 2014.
	Presentations: CAC (October 14), AAFS (February 2017)
	Publication: *Analytical Scientist* Feb 2015 [8]
Stage 3: February 2017: (GUARDion GC/MS by Perkin-Elmer/Smiths Detection, SPME sampling)	
	Training of private-sector investigator.
	Smiths withdraws GUARDion support.
Stage 4: October 2017 – September 2018. Torion® T9 GC/MS (Perkin-Elmer), SPME sampling	
	Private-sector investigator testing at fire scenes with analyses by private-sector fire debris laboratory
	Presentations IPTES (NIJ conference), Arlington VA, January 2018
	Publications: IPTES proceedings [10]
Stage 5: July 2019 – January 2020: Griffin G510 GC/MS by FLIR®/Air Confirm® sampling	
	Scene examinations continue with private-sector investigators. Area of interest defined by canine alert or fire pattern.
	Live structure post-flashover burn tests: UVU (July 2019) and CCAI (San Luis Obispo CA) September 2019.
	Presentation: CCAI: Air Confirm® sampling method introduced to fire investigators
	CCAI samples successfully analyzed by G510 using Air Confirm®, Vallejo CA Jan 2020 and compared to forensic laboratory library data.

Significant data were generated and analyzed as the new sponsor was interested in developing GC/MS methods specific to fire investigation. All previous GC/MS methods used were focused on HazMat/WMD methods that prioritized threat agents.

A presentation at the National Institute of Justice (NIJ), Impression Pattern and Trace Evidence Symposium (IPTES),

in January of 2018 provided evidence that GC/MS field data, and most importantly, the process for obtaining the data, was defensible. [10] The GC/MS instrument sponsor implemented a new operating method in April of 2018, and a decision was made to suspend the field testing until the fire/arson field methods were fully developed. Finally, in Stage 5, support was gained from NIJ via the Research Triangle Institute (RTI) in July 2019 to fund the tests and evaluations reported here.

The initial testing of Stage 5 was held at Utah Valley University - Provo (UVU) in July of 2019. There, a large, furnished fire test room with four small deposits of ignitable liquids on the carpet was set alight and allowed to progress well past flashover. Equipment issues prevented on-scene GC/MS analysis. In September of 2019, the authors incorporated the research objectives into full-scale live burns conducted at the California Conference of Arson Investigators (CCAI) in San Luis Obispo, CA. Small amounts of various ignitable liquids were placed in furnished rooms. The rooms were set alight and allowed to burn to full room involvement (post-flashover). Samples were taken based on "sniffer" readings (ppbRae®) and subjected to analysis by the Griffin G510 system using air sampling. There were no useful GC/MS data gathered at the time of these tests as equipment reliability (failure to clear and performance validation) was again an issue when using the SPME sampling function. [11]

The equipment issues at CCAI led to an adjustment in sampling procedures to take advantage of a feature of the Griffin G510® which produces useful data in a ten-minute analysis time. Previous GC/MS instruments used in the research utilized SPME sampling techniques exclusively. The Griffin G510® incorporated an Air Confirm® method that used a Tenax®/Carboxen dual-bed trap as a pre-concentrator, providing the ability to pull a concentrated air sample directly into the instrument.

The shift away from SPME to Air Confirm® required supplemental training. The Griffin G510® consultant trainer used at the UVU testing in July 2019 trained two additional private-sector investigators who were able to demonstrate competency getting data following the sampling protocol at fire scenes.

From late October 2019 through January 2020, the private fire investigation firm conducted numerous fire investigations using the sampling protocol and obtained data from thirty fire scenes that were sent to an accredited private fire debris laboratory for GC/MS analysis. Evidentiary samples were obtained, and laboratory GC/MS data generated. Practical difficulties and equipment reliability issues were the determining factors to centrally locate the Griffin G510® at the firm's headquarters to test "head space" samples from the evidence cans prior to sending them to the lab for definitive testing. Just prior to the final meeting, those investigators gathered additional GC/MS data from selected evidence cans that had been generated throughout the project and during the CCAI fire tests in September 2019. All the Griffin G510® data was then accessed by FLIR® subject matter experts, analyzed, and compared to the fire debris lab data by the authors.

Results

Limited success was achieved at obtaining useful data at fire scenes with the Griffin G510® until such time as the FLIR® analysts evaluated the testing protocol and refined the GC/MS method, simplifying the output making the application more user friendly for the field investigator. More than sixty fire scene samples and standards were tested on the field unit and confirmed in certified forensic laboratories specializing in fire debris analysis. The data assessment was performed in accordance with ASTM E1618 for identification. [12]

The data collected from the field instruments was compared with the forensic lab data to determine the sensitivity, consistency, and range of products amenable to field testing. The sensitivity of the instruments tested was found to be comparable to that of the laboratory mass spectrometers. Data consistency of the field units is again somewhat limited by the sampling method with more variation in component retention times than that found in the forensic lab. The limiting aspect of the field units appears more based on the sample collection methods used (SPME and Air Confirm®). Both methods collect samples at ambient temperatures and rely on the volatility of the ignitable liquid involved being tested and, therefore, are more sensitive for the more volatile ignitable liquids. As a result, light and medium ignitable liquids volatizing at ordinary ambient temperatures are more readily detected. Heavy petroleum distillates are not effectively identified by these methods and show atypical and skewed chromatograms, complicating their identification. Components having molecular weights greater than n-dodecane, (with a carbon chain of 12 carbons) are not readily detectable in samples tested at ambient temperatures (under 25°C). This can be best shown in the comparison of field chromatograms with fire debris lab analyses (See Figures 4-11).

Discussion

Two main modes of mass spectrum analysis were evaluated in the field units used: ion trap and quadrupole. Both methods have a long-established presence in the forensic community and have been used for decades.

The ion trap method used in the Griffin G510© typically has the advantage of greater sensitivity over quadrupole. Its main disadvantage is that the mass fragmentation data collected is typically compared with standard libraries collected using the more common quadrupole mass spectrometers. Because of subtle differences in the mass fragmentation patterns between methods, computer matching is somewhat less reliable when using the ion trap. The ASTM E1618 method for the identification of ignitable liquids does not rely on computer identification of all peaks but rather emphasizes the significance of peak patterns produced by major chemical species - alkanes (aliphatics), aromatics, cycloparaffins, etc.

The quadrupole method is the most common type of mass spectrometer used in the forensic labs. Most computer libraries are based on quadrupole instrument data for computer searching, so matching is optimal when

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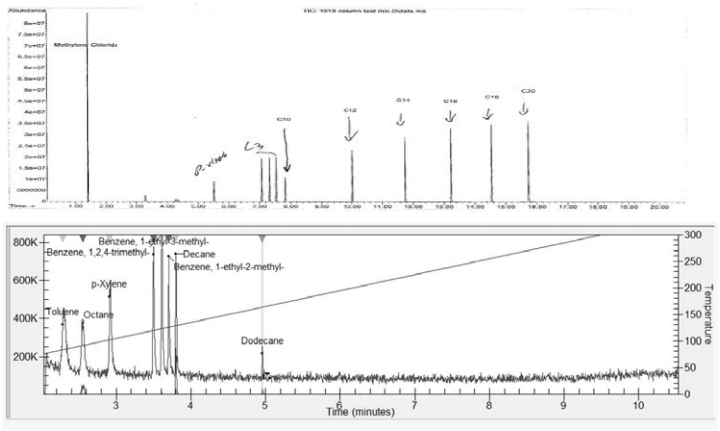

Figure 4. Comparing gas chromatograms of ASTM E1618 Test Mix by laboratory Agilent® 7890A GC/5975C MS liquid injection (top) and Griffin G510® air sample (bottom). (FLIR®). The diagonal line on the G510® plot represents the temperature program of the GC.
Note absence of compounds heavier than n-dodecane (C12) due to ambient temperature sampling conditions.

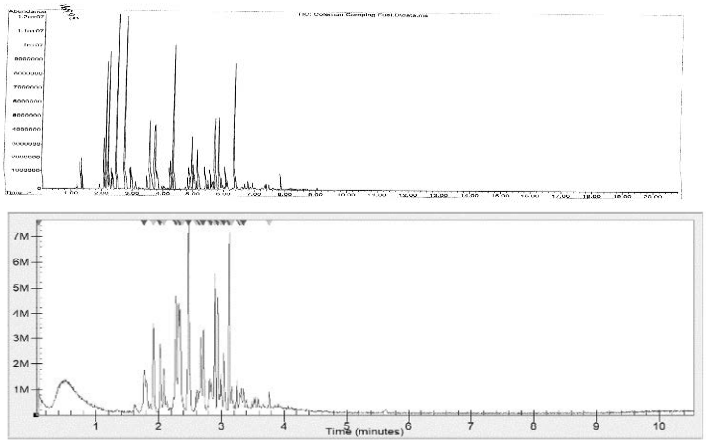

Figure 5. Comparing Coleman Fuel® analyzed by laboratory Agilent® GC liquid injection (top) and Griffin G510® liquid injection (bottom). (FLIR®). Note shifted retention times but good reproducibility of pattern of major peaks.

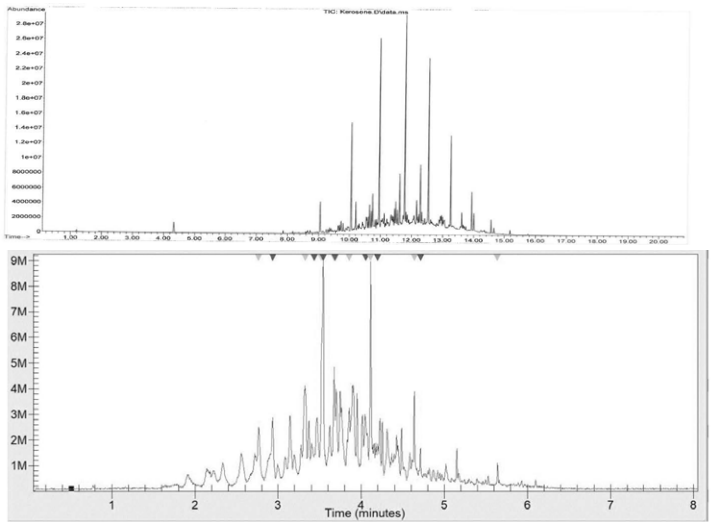

Figure 6. Comparing CCAI Can #3(9/19) (Kerosene) by laboratory Agilent® GC liquid injection (top) and Griffin G510® air sample (bottom). (FLIR®). Note drop-off of later eluting components in the G510® data.

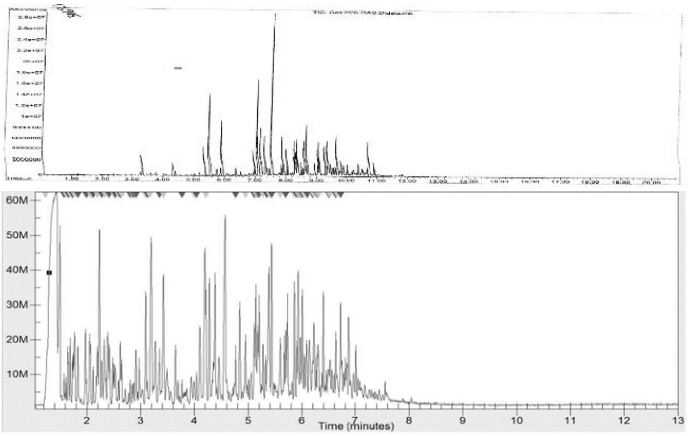

Figure 7. Comparing 75% evaporated Gasoline laboratory Agilent® GC liquid injection (top) and Griffin G510® air sample, from UVU test (bottom). (FLIR®).
Note offset timeline in G510® data plot, but good peak pattern agreement above 2.2min of G510 data. Source of the lightest compounds in the G510® analysis is unknown.

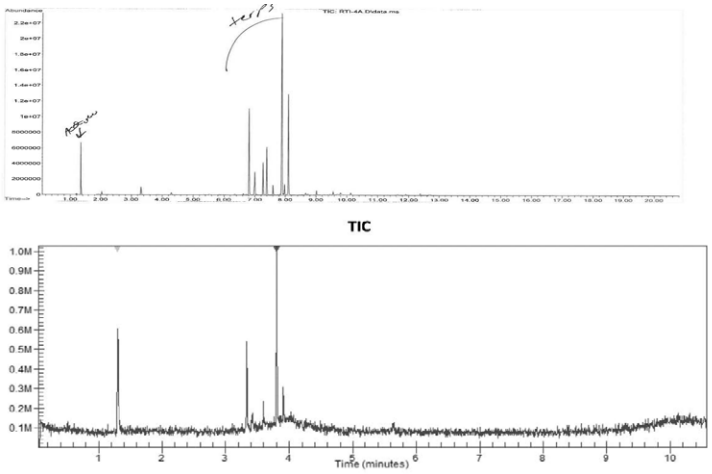

Figure 8. Comparing CCAI (9/19) Can #4: Acetone with pinenes from wood substrate. Laboratory analysis by Agilent® GC using ASTM E1412 (top) and Griffin G510® air sample, from Vallejo testing (1/20) (bottom). (FLIR®).
TIC = total ion count.

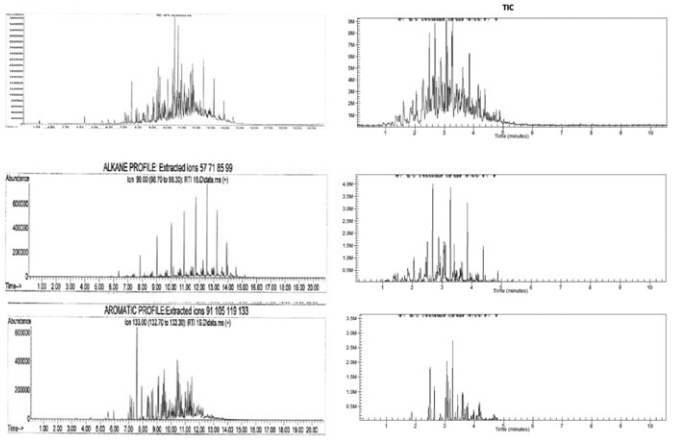

Figure 9. Comparing CCAI (9/19) Can #16 (Diesel fuel) using ASTM E1412 on laboratory Agilent® GC/MS (left), and Griffin G510® air sample (right) . Total ion count (top), Alkane MS profile (middle) and Aromatic MS profile (bottom). (FLIR®).
Note decreased peak heights above 4min on G510® analysis compared to profile of peaks from ASTM 1412 analysis.

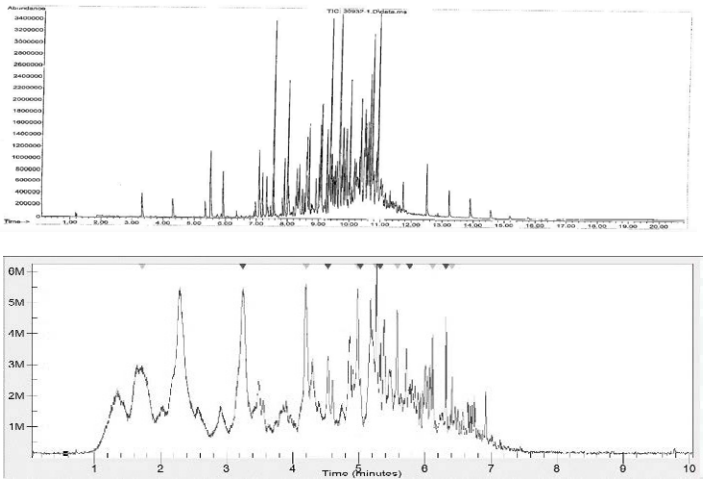

Figure 10. Comparing Fire scene #134: Evaporated Gasoline, by laboratory Agilent® GC using ASTM E1412 (top) and Griffin G510® air sample (bottom). (FLIR®). Early eluting peaks distorted on G510 by air sampling collection method.

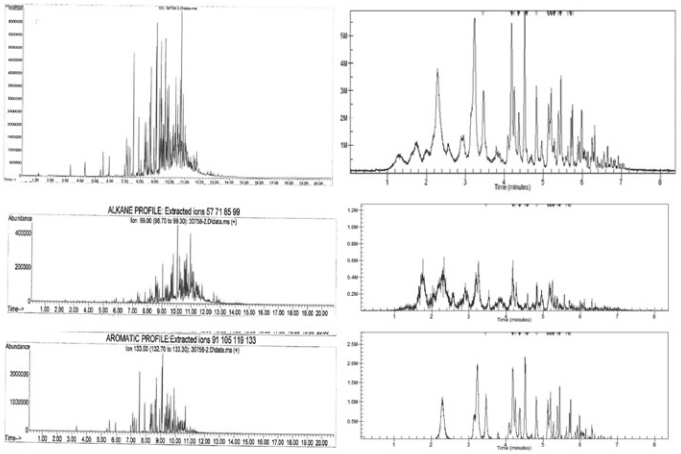

Figure 11. Comparing Fire scene #139 (gasoline) using ASTM E1412 on laboratory Agilent® GC/MS (left) and Griffin G510® air sample (right) .Total ion count (top), Alkane MS profile (middle) and Aromatic MS profile (bottom). (FLIR®). Good reproducibility of TIC and aromatic peaks. Some distortion of the alkanes in G510® due to low concentration.

using a quadrupole instrument. Being most common, lab operators are more familiar with quadrupole use and maintenance.

As a result, there is no clear-cut advantage of one type of mass spectrometer detection over the other and often comes down to operator preference, instrument integrity, and ease of operation. Both of the field GC/MS systems used over the course of this research were able to produce chromatographic separations and MS data comparable to those of the forensic lab bench method in 10-12 minutes analysis time.

All of the portable GC/MS systems evaluated in this project were designed for hazardous materials/ WMD response detection for military, fire, or police agencies and many have been deployed successfully for that purpose.[8] It must be noted that those detections typically involve one or two compounds (such as a virus, toxin, or chemical agent). This means that the software provided has to search one or two peaks from the GC and identify them by their mass spectrum from a built-in library of possible threat agents. The identification of ignitable liquids is usually very different. Most of the ignitable liquids of interest in fires are mixtures of anywhere from 20 to more than 200 compounds, all of which are hydrocarbons with very similar MS profiles. The identification of ignitable liquids in fire debris depends first on a search for distinctive peak patterns followed by a MS search to characterize what hydrocarbon families (alkanes, aromatics, cycloparaffins, etc.) are present. This is the ASTM Standard E1618 method required in certified fire debris laboratories. [12]

The ability of forensic examiners to identify petroleum products by GC/MS is a skill that is developed over weeks to years of comparisons to a library of reference materials and testing of a wide variety of products. Training for operators of these field systems was largely limited to making the system work in the field with some success. However, conveying the principles of pattern recognition to the investigator/operator by electronic means has proven to be a primary weakness of this application. Plans then turned to relaying the GC and MS data collected via digital link to a qualified forensic chemist to make the actual identification. This is often done among forensic labs as today's GC/MS files can be transferred easily on-line to another user. For this approach to succeed for in-field identifications it would require an accredited expert to be available on-line. This is not easily done but would provide the on-scene investigator a court-acceptable analysis available before leaving the scene. It is suggested that future field projects investigate these possibilities.

Many public agency forensic labs are under-staffed and fire debris cases are usually given the lowest priority and some labs are no longer offering fire debris analysis. Many public sector investigators are turning to private labs who can give 24-48 hour turn-around on a pay-as-you-go basis. Having a functional GC/MS at the fire scene would give investigators on-demand access to interpretation of results by an accredited fire debris analyst who could access the data.

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Fire Investigator Perspective

The fire investigators in this study agreed that the team approach currently in use, employing a canine search, screening by a PID, collection, and analysis, is efficient and effective. They agreed that there is a future for getting GC/MS data sent from the field to a lab via a data link (to be developed and evaluated) for examination by a verified analyst. Issues with degradation of the sample and lack of timely response from many public safety laboratories are the primary factors in this determination. Notably, quality assurance or referee analysis of lab results can be conducted today from remote locations outside of the lab with on-line transfer of GC/MS data.

The costs for fire investigators to acquire the equipment and training necessary to sustain field ready GC/MS are formidable. The argument is made that public safety entities can access the capability today by utilizing existing resources. Type I Hazardous Materials Teams and Civil Support Teams (CST) have portable GC/MS capability which can respond to a scene following specific procedures.[8] High consequence incidents where public safety can benefit from the confirmation of the presence and identification of an ignitable liquid support employing these current capabilities.

Conclusions

As a primary consensus of this study, it was agreed that field-portable GC/MS systems as tested here are capable of GC separations, reproducible retention times, and sensitivity comparable to forensic lab bench systems. Interpretation of that data is still a problem for the field investigator, however. Without significant improvements in training of the field operators and timely technical support to address equipment issues, the application of field portable GC/MS for fire investigation has proven to be problematic. However, the future of field-portable GC/MS providing useful data for the scene investigator is promising. With improvements in methods, reliability, and remote technical support (possibly from a certified fire debris analyst), the fire investigator could have confirmation of the presence of ignitable liquid residues useful for furtherance of the criminal case provided from the scene. Due to the oversaturation and sample loss issues of SPME sampling of volatiles from fire debris, SPME sampling does not appear to be as easily used in the field as does the Air Confirm© (air sampling) method tested on the Griffin G510©. The limitation on both these collection systems is that they can only sample at ambient temperatures. This means that the heavier (i.e., less volatile) petroleum products may avoid detection (without collection and laboratory analysis employing heating).

This project was not to consider the replacement of either canines or forensic lab support but rather to see how field-available GC/MS data could improve investigations. The proper use of the PID in support of canine alerts and investigation techniques is providing a high degree of confidence that the evidentiary sample being sent to the lab contains an ignitable liquid residue. During Stage 5, 139 fire scenes were processed by the fire investigation firm, 26 of which were processed utilizing the canine and PID protocol, accompanied by the "headspace cup method". All of the evidentiary samples taken that had headspace PID readings above 10ppm were confirmed positive upon analysis in forensic laboratories specializing in fire debris analysis.

Recommendations

A limiting factor in the field application of GC/MS is that the data produced must be analyzed by a trained GC/MS specialist to confirm the identification of the ignitable liquid, similar to current lab techniques. It is recommended fire debris lab analysts explore implementing remote procedures to evaluate GC/MS data produced at fire scenes.

It is recommended that fire debris analysis methods continue to evolve to include automated interpretation software enhancing the field application of GC/MS to fire evidence.

Future research efforts should focus on continuing improvements in field portable GC/MS methods and the impacts of having accurate GC/MS data while at the fire scene, specifically at high consequence incidents. It is also recommended that new generations of PID “sniffers” such as the ppbRAE 3000® tested here be deployed at all fire scene investigations to supplement canine team searches. Photo ionization detectors possess a selectivity for hydrocarbons, speed of response, and sensitivity that make them essential to effective fire investigations.

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