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Detection and characterization of volatile organic compounds from burned human and animal remains in fire debris

John D. DeHaan [a,*], Eimi I. Taormina [b,1], David J. Brien [c]

[a] Fire-Ex Forensics, 3505 Sonoma Blvd, Ste. 20-314, Vallejo, CA 94590, USA
[b] Forensic Science Graduate Program, University of California, Davis, One Shields Avenue, Davis, CA 95616, USA
[c] EFI Global, 555 Menlo Drive, Suite D, Rocklin, CA 95765, USA

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ABSTRACT

Debris collected from various test sites where mammalian remains (human and porcine) had been burned in a variety of full-scale fire scenarios was evaluated for the presence of volatile residues that could be characteristic of those remains. Levels of volatiles were measured using the method commonly used for fire debris analysis: gas chromatography–mass spectrometry. Homologous *n*-aldehydes (from *n*-pentanal to *n*-nonanal) proved to be a significant indicator of the presence of burned animal tissue as they were observed in nearly all of the samples. Such aldehydes are created by the combustion of animal fats. One aldehyde, *n*-hexanal, appeared more frequently than the other aldehydes, *n*-pentanal, *n*-heptanal, *n*-octanal, and *n*-nonanal. Ethanol was detected in two-thirds of the samples, while acetone appeared in about three-fourths of the samples, but both were detected at much lower concentrations than *n*-hexanal. These appear to have been combustion products of the substrates on which each body burned, rather than originating from the combustion of the body. There appeared to be no qualitative distinction between volatile products produced from burned porcine carcasses and those from human cadavers. Since a homologous series of C_5–C_9*n*-aldehydes is not produced as a dominant species by the pyrolysis or combustion of any normally encountered substrate (carpet, bedding, wood products or upholstery), their detection by normal fire debris methods appears to be a valid indicator of the presence of burned animal remains. These data will also provide guidance to fire debris analysts as to the nature of volatiles associated with the combustion of human bodies in real-world fires.

1. Introduction

When a very badly burned body is found in a fire or a presumptive examination for ignitable liquids (such as an electronic sniffer or accelerant detection canine) yields a positive indication, samples from under or around the body are often collected and analyzed for the presence of residues of ignitable liquids. Comparison to the volatile components of pyrolysis products of materials known to be involved is necessary to establish that the volatiles detected are, indeed, foreign and therefore indicative of the presence of a possible ignitable liquid used as an accelerant. To accomplish this, fire debris analysts prepare extensive libraries of chromatographic data on both known ignitable liquids and exemplar or comparison specimens (both burned and unburned) that may generate volatiles as possible interferences (such as the Ignitable Liquid Reference Database and Substrate Database maintained by the National Center for Forensic Sciences)[1]. All experienced analysts have collections of data on burned carpet, upholstery, clothing, furniture, and structural materials but very few have access to 'standards' of burned human tissue. In addition, when a body is moved post-fire, either by structural collapse or deliberate human act, it may be important to the reconstruction of the fire events to identify its previous location in a structure, vehicle or even wildland fire. Knowing what volatiles might be produced by the combustion of human body is invaluable to proper interpretation of GC–MS results of debris analysis carried out by normal fire debris analytical methods (e.g. ASTM E1412 and E1618)[2,3].

A previous study identified a characteristic combination of homologous series (*n*-alkanes, *n*-alkenes, and *n*-aldehydes, dominated by the *n*-aldehydes) produced by the open air combustion of human and animal fats in a micro-furnace [4]. Such pyrolysis is a simplification of the pyrolysis (and oxygenated pyrolysis) and combustion that occurs at various temperatures during an actual fire. While various authors have reported the detection of isolated volatile *n*-aldehydes from normal human skin or decomposition of buried human remains, but not a homologous series[5,6,7,8].The current study made use of a unique opportunity to collect debris from under real, unembalmed, human cadavers burned under a variety of real-world fire conditions. These fires also included a number of similar fires that involved fresh pig carcasses. These fires

* Corresponding author.
E-mail addresses: jddehaan@fire-exforensics.com (J.D. DeHaan), eimitaormina@gmail.com (E.I. Taormina), David_Brien@efiglobal.com (D.J. Brien).
[1] Permanent Address: 1041 Greene Terrace Davis, CA 95618, USA.

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were carried out as practical exercises as part of the Forensic Fire Death Investigation Course (FFDIC) conducted each year by SLOFIST, Inc. (San Luis Obispo Fire Investigation Strike Team). All previously published studies of volatile residues involved the combustion of bodies under artificial conditions (such as a commercial crematorium) or analysis of small samples of subcutaneous fat under instrumental analytical (non-fire) conditions (micro furnace)[4,9]. By comparing these data sets, it was found that the combustion of porcine and human remains produced combinations of volatiles that were indistinguishable from each other based on the GC–MS protocols in use in most forensic laboratories. The volatiles, however, appeared to be sufficiently characteristic to permit distinction of 'body related' samples from those not involving bodies.

This study was proposed to see if *n*-aldehydes or other volatiles were a reliable indicator of burned remains in a real-world fire and to see what volatiles were produced that could constitute a background when a human or animal body was a significant fuel burned. Unfortunately, research is very limited regarding testing debris from free-burning, real-world fires involving human remains. Forensic scientists and fire experts have staged limited fire tests involving human and animal remains in various situations as part of courses or seminars to replicate real-world fires but with no debris analysis.

In this study, samples of debris from beneath burned bodies from various FFDIC scenes, from over a period of seven years, including car fires and house fires, were analyzed for specific volatile compounds produced from pyrolyzed materials. Aldehydes were chosen as the primary indicator for the combustion of body fat because they have been proven to be products of pyrolysis of triglyceride-based fats [9,10] and were reliably detected after pyrolysis of human and animal fat [4]. Aldehydes were one of the most prominent chemical groups seen in these controlled-environment experiments. Secondary indicators included several light volatiles, including ethanol and acetone. Ethanol was chosen as an indicator for biological material because it is produced by many species of microorganisms that play a role in postmortem decay [10,11], while acetone was chosen because of recent disputes about its role in fire debris involving human remains [12]. Homologous series of *n*-alkanes and *n*-alkenes, dienes, and simple aromatics were also detected. However, these compounds are often produced by the pyrolysis of normal combustibles (polymers) in structure fires, making them less useful for discriminating animal residues in fire debris.

To test additional conditions that could apply to crime scenes, samples from fires started with petroleum-product-based accelerants were compared against samples from non-accelerated fires to see if the presence of body-related volatiles would interfere in the detection of petroleum-based accelerants and vice versa.

2. Materials and methods

2.1. Fire tests

For each FFDIC class, a series of full-scale fire scenarios is created as practical exercises for the students. These include vehicle fires, structure fires, dumpster fires and rubbish pile fires. Unembalmed human cadavers refrigerated at near 0 °C, are dressed and positioned in various positions suitable for the scenario[2]. In a limited number of scenarios, the carcasses of freshly slaughtered adult pigs were substituted for human cadavers. The fires were started by a variety of means, either direct open flame or with the assistance of a liter of 50/50 gasoline/heavy petroleum distillate mixture. Fires were extinguished by water spray or in some cases, allowed to burn to self-extinguishment. The scenarios in 2008–2011 involved are shown in Table 1A.

A preliminary evaluation of the data from 2008 to 2011, Phase 1, revealed variations in the volatile signatures that were suspected of being from contributions of the substrates on which each body was positioned during the fire. The sixteen Phase 2 tests (2013–2014) included documentation of the substrates and collection of reference (pre-fire) samples for later identification. The scenarios for Phase 2 are shown in Tables 1B and 1C.

During the 2008 class, 11 of the test scenarios included fresh pig carcasses (from a local slaughterhouse), while seven involved unembalmed human remains. In 2009, 2010, 2011 and 2013, only unembalmed human cadavers from in-care hospital deaths were used. In 2014, two fresh pig carcasses were exposed to fire under the same

Table 1A
Descriptions of various fire scenes at FFDIC (Phase 1- 2008–2011).

Scene numbers	Species	Samples
2008		
1. Bedroom - on bed	Pig	O
2. Living room - human torso & head on sofa with synthetic blanket; 14 minutes post flashover	Human	E, J
3. Vehicle - white station wagon with pigs in driver's seat & back seat, 14 minutes post flashover	Pig	B,C, D, G
4. Small cubicle 4′ × 4′ × 8′ (3 sided) - human in cotton sweat clothes on box spring mattress and synthetic carpet. Flashover then allowed to burn to self-extinguish at 7.5 h	Human	K, L, M
5. Vehicle - four door sedan with pig in driver's seat	Pig	R
6. Vehicle - four door sedan with pigs in driver's seat & back seat	Pig	N
7. Vehicle - four door sedan with pig in driver's seat	Pig	I
8. Vehicle - four door sedan with pig in driver's seat	Pig	H, P, S
9. Vehicle - station wagon with human torso and head in driver's seat	Human	F, Q
All of the above fire tests were allowed to develop to sustained flashover conditions.		
2009		
1. Three sided room - human on bed, cotton clothes and blankets. Brief flashover. Body allowed to burn to self--extinguish at 6.25 h.	Human	Y, BB
2. Vehicle - sedan dropped from crane then burned with human in driver's seat. 43 minutes/22 minutes post-flashover	Human	Z
3. Vehicle - SUV with human in cargo area (carpet) wool blanket; 25 minutes flashover.	Human	T, DD
4. Travel trailer - clothed human in bed; 15 minutes post-flashover	Human	U
5. Living room - oxygen enhanced with human torso on sofa; 13 min (no flashover)	Human	V
6. Dumpster - nude human with knife and axe trauma wrapped in plastic (polypropylene) and carpet + mattress	Human	AA
7. Kitchen - human on gas stove. Minimal fire; 11 min	Human	X
8. Plane crash into 2 room structure - human on plane and human on sofa in adjoining room, av gas start; 11 minutes post-flashover fire.	Human	W
9. Three sided cubicle - human on box spring. Flashover demo; 10 min	Human	CC – Demo
2010		
1. Room 14′ × 12′ - human lying over floor furnace, cotton robe, fire limited to body; 4 h	Human	1,3
2. Metal garden shed 6′ × 9′ - stabbed human on floor, nude. Wood Pest/PP	Human	2
2011		
1. Roadside dump - human shot, burned on ground with wood pallets, brush and carpet; 3 h	Human	4
2. Human (with visible decomposition) wrapped in blanket with electric heater. Limited fire; 4 h	Human	5
3. Tent - human in tent – plastic tent, cotton blankets, and mattress, cigarette ignition; 2.5 hours flaming fire	Human	6
4. Vehicle - human in driver's seat (crash); 12 min	Human	7

[2] The cadavers were obtained by the Medical Education and Research Institute, Memphis, TN as specified donations and provided to the San Luis Obispo County Sheriff Coroner Office in accordance with applicable medical ethical guidelines for use in the FFDIC class only. At the end of the course, the remains were resealed in their original body bags and transported back to MERI for cremation.