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Detection and Characterization of Gasoline based Polycyclic Aromatic Hydrocarbons on Different Materials by Gas Chromatography-Mass Spectrometry

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Polycyclic aromatic hydrocarbons (PAHs) profile by gas-chromatography-mass spectrometry were recently used for the identification of sources of contamination in environmental forensic investigations. In present study, an effort is given to utilize gas chromatography-mass spectroscopy to obtain PAHs profile that could help forensic scientist in selection of evidence at the scene of fire. In forensic laboratories, the main evidence received in fire burning cases are fire debris which consists of soil, wood, paper, cloth *etc.* as a piece of individual evidence or mixture. In fire investigation, the type of material collected from the crime scene affects the investigation hence present study focused on which type of material is more suitable while utilizing a polycyclic aromatic hydrocarbon as a source identifier. Total of nine different materials like paper, cardboard, foam, cloth, metal, hair, soil, meat and wood were selected and these are burned with gasoline in partial burning and complete burning conditions. Debris obtained sonicated at room temperature and concentration of 18 PAHs were determined with gas chromatography-mass spectrometry. Results obtained were analyzed with the Principal Component Analysis (PCA) technique to generate a profile of PAHs. It is concluded that partially burned samples provide more information about the use of ignitable liquid to commit the crime as compared to completely burned samples. The meat, hair, metal and soil material provide more information about the presence of ignitable liquid based on the 18 PAHs concentration profile.

Keywords: Fire investigation, Gasoline, Polycyclic Aromatic hydrocarbon, Principal component analysis.

INTRODUCTION

Fire burning cases are most challenging in the field of forensics mainly where the lability is to prove whether the fire is intentional or accidental. Arson is deliberate willful and malicious burning and setting someone's property on fire with some intention [1,2]. Arson is a serious crime that affects individuals and society with high cost, loss of life and property damage [3]. In such fire burning cases, the different types of inflammable solvents like gasoline, diesel, kerosene, acetone, *etc.* are used which are most commonly available. In such cases source identification is required to prove the liability of crime. As a massive process, fire destroys everything in its path, including the evidence needed to prove a criminal act. If burning is accidental and occurred due to spillage of any chemical which later comes in contact with heat that causes massive fire even in such cases source and cause of fire determination is required and due to fire's destructive nature, most of the evidence gets lost. In forensic laboratory most commonly, evidence received is crime scene debris which consists of soil, wood, paper, cloth stone, *etc.*, as individual evidence or mixture.

The burden of crime is depending on the identification of traces of ignitable liquid used during a fire, but it is difficult to identify traces of ignitable liquid due to various conditions like area under fire, type of ignitable liquids, amount of ignitable liquid used, type of fire extinguisher used like the use of water, gases to extinguish the fire, time and extent of the fire, atmospheric conditions, time of collection of samples, preservation of sample and time of analysis of the sample. All these factors affect the identification of traces of ignitable liquid because ignitable liquids most of the time are volatile and easily evaporate within a specific limit, affecting the whole analysis. Routine fire ignitable liquid analysis is not useful due to the above-mentioned factor. The traditional identification method is based on extraction of fire debris, analysis by GC-FID and GC-MS instrument and comparing of obtained spectra against standard prepared in the same condition.

The recent study focuses on the use of polycyclic aromatic hydrocarbons (PAHs) for source identification in oil spill cases in environmental forensics to prove the liability of contamination of any area due to industrial waste or any other activity. Polycyclic aromatic hydrocarbons are the ubiquitous micropollutants [4-7]. They are persistent, toxic, carcinogenic, mutagenic and teratogenic and most of them can cause DNA damage [8-11]. PAHs are colourless to white or pale yellowish-green in colour due to its low solubility and high octanol-water partition coefficient and undergo long-range transport it accumulates in organisms [12-14]. In contrast to heavy molecular weight PAHs found in particulate matter, low molecular weight PAHs are more volatile and thus easily discovered in the gaseous phase, and they are less carcinogenic [15]. PAHs are gaseous at high temperatures but when it cools downs settle on the ground leading to transportation [16].

Polycyclic aromatic hydrocarbons (PAHs) pattern study is also used in compliance evaluation and risk assessment [17]. US Environmental Protection Agency has listed 16 PAHs a major pollutants [14,18,19], which are detected in food samples like fried, roasted, grilled & smoked meat and fish samples [20]. In marine environment contamination PAHs are reported at a severe level that causes cancer in various aquatic animals [9]. In an environmental forensics PAHS are detected in air, soil, particulate matter, food material, river water, sewage sludge, *etc*. [21,22]. They are classified according to the number of a benzene ring attached. Contribution of these 2-ring, 3-ring, 4-ring, 5-ring and 6-ring PAHs in environment are 6%, 50%, 13%, 13% and 18%, respectively [23].

For source identification sum of high molecular weight and sum of low molecular weight, PAHs are used to identify petrogenic and pyrogenic sources as petrogenic sources mainly consist of 2-3 ring PAHs compounds dominated by low molecular weight PAHs, however pyrogenic sources mainly consist of more than 4-ring PAHs compounds dominated by high molecular weight PAHs. Therefore, the ratio of low molecular weight PAHs to high molecular weight PAHs < 1 indicates pyrogenic sources, whereas if the ratio is > 1 indicates petrogenic sources [24].

Previously simulated fire combustion experiments were conducted wherein combustion of gasoline on PVC plastic carpet was performed in which characteristic PAHs profile obtained from gasoline combustion product were compared with that of mixed combustion residue of PVC plastic carpet and gasoline with GC-MS that improves detection and identification characteristics of gasoline as an ignitable liquid in arson cases. at the scene of the crime various combustible materials like wood furniture, decorative materials, cotton, hemp, carpet and electric components and various plastic components like Polypropylene (PP), polyethylene (PE), polystyrene (PS). Polyvinyl chloride (PVC) andpolyethene terephthalate (PET) affect the detection and identification and quantification of components [25]. A similar study was conducted on gasoline soot wherein 19 PAHs were detected in gasoline soot which is extracted with solid-phase microextraction technique and analyzed with GC-MS. PAHs are successfully used in the identification of gasoline soot [26].

The selection of the type of fire debris at the scene of the crime is too important because the whole work of analysis is depending on the sample material selected for analysis. Most of the time porous substances like wood, paper, cardboard and cloth are suitable for collection because most of the fire ignitable liquids are absorbed in them whereas metal and glass are fewer choices for selection because of their non-porous nature. It was found that window glass does not absorb any gaseous compounds hence helping in identification whereas the porous nature of sofa foam absorbed most of the gaseous compounds that interfere with identification [27]. However, soot deposited on a non-porous material helps in the identification of compounds [28].

The present study replaces the detection of aliphatic and aromatic compounds for the identification of ignitable liquid by generating a polycyclic aromatic compound qualitative and quantitative profile by GC-MS. The present study helps in the correct identification of matrices for the identification of ignitable liquid based on its PAHs profile by gas chromatography-mass spectrometry. The present study also focused on how different surface matrices with different time intervals of burning to affect the PAHs concentration in gasoline burning.

EXPERIMENTAL

Samples preparation: In present study, 9 different surface matrices *viz.* paper, cardboard, foam, wood, plastic gunny bag, hair, meat and soil were selected. Gasoline is purchased from the local HP gas center, Mumbai, India. Gasoline (20 mL) was added to each material and first burned completely until it ceased to fire itself. In second condition, on each material 20 mL of gasoline was added and partially burned (half the time of complete burning) after that each sample was stored in a pre-cleaned glass jar with a metal screw cap lid and stored in a refrigerator until the analysis. Each complete burning sample obtained after burning paper, cardboard, foam, cloth, metal, hair, wood, soil and meat labeled as C-1, C-2, C-3, C-4, C-5, C-6, C-7, C-8 and C-9, respectively, whereas each partially burned sample obtained after partial burning of paper, cardboard, foam, cloth, metal, hair, wood, soil and meat labeled as P-1, P-2, P-3, P-4, P-5, P-6, P-7, P-8 and P-9, respectively.

Sample extraction: Each sample (2 g) was added to 30 mL mixture of hexane:acetone:dichloromethane in 1:1:1 ratio in a conical flask and then covered with glass lid and kept in ultra sonicator at room temperature for 20 min. Then samples were filtered using Whatman filter paper and evaporated to make a final concentration of around 10 mL and finally stored in sample storing vials and kept in the refrigerator until the GC-MS analysis. A 18 EPA polycyclic aromatic hydrocarbon mixture certified reference material CRM 47543 was purchased from SUPELCO sigma Aldrich with 2000 µg mL^{-1} each compound present in 1 mL of a standard ampule in a mixture of benzene:dichloromethane (50:50). Certified reference material consist of mixture of acenaphthene, acenaphthylene, anthracene, benz[*a*]anthracene, benzo[*b*]fluoranthene, beno[*k*]-fluoranthene, benzo[*g*,*h*,*i*]perylene, benzo[*a*]pyrene, chrysene, dibenz[*a*,*h*]anthracene, fluoranthene, fluorene, indeno[1,2,3-*cd*]-pyrene, 1-methylnapthalene, 2-methylnaphthalene, naphthalene, phenanthrene and pyrene. For quantitative estimation 8 points calibration curve were prepared which consist of 10, 50, 100, 200, 500, 1000, 1500 and 2000 µg mL^{-1} concentrations.

GC-MS analysis: Thermo-Fisher scientific GC-MS system was used which consist of a Trace 1310 GC system and TSQ 9000 triple quadrupole mass system and connected with AL/AS 1310 series autosampler. Electron ionization mode was used for ionization. Ion source temperature set at 260 ºC. TG 17 MS column with 20 m × 0.25 mm × 0.25 µm dimension was used. GC frontlet temperature set at 280 ºC. Initial temperature set at 90 ºC with increasing temperature with rate 9.5 ºC/min hold for 20 min when the temperature reached 280 ºC hold it for next 20 min. Total run time was 40 min for each sample run thrice and averages were calculated to find the final value for each standard. In a similar procedure, all samples were analyzed with GC-MS. For the identification of each compound retention time was obtained for each standard component searched against the NIST library and each component was identified same retention time used for the identification of components in each sample. Calibration curves were obtained for each standard component. Retention time and % correlation coefficient for each standard component are given in Table-1. Linear line passing form origin obtained to determine the linearity of calibration curve for each component of standard given in Figs. 1 and 2.

TABLE-1
RETENTION TIME AND % CORRELATION COEFFICIENT
FOR EACH COMPONENT OF STANDARD

S. No.	Peak name	Retention time	Correlation coefficient
1	Naphthalene	5.110	0.994
2	2-Methylnaphthalene	6.350	0.995
3	1-Methylnaphthalene	6.720	0.995
4	Acenaphthalene	8.890	0.997
5	Acenaphthene	9.200	0.997
6	Fluorene	10.320	0.997
7	Phenanthrene	12.870	0.997
8	Anthracene	12.950	0.997
9	Fluoranthene	15.880	0.997
10	Pyrene	16.580	0.997
11	Benzo[*a*]anthracene	19.490	0.997
12	Chrysene	19.700	0.997
13	Benzo[*b*]fluoranthene	22.640	0.996
14	Benzo[*k*]fluoranthene	22.750	0.996
15	Benzo[*a*]pyrene	24.370	0.997
16	Indeno[1,2,3-*cd*]pyrene	30.840	0.996
17	Dibenz[*a,h*]anthracene	31.150	0.997
18	Benzo[*g,h,I*]perylene	33.600	0.995

RESULTS AND DISCUSSION

A variety of material or substrates encounter at the scene of the crime like cloth, paper, cardboard, metal, *etc.* most commonly materiales encounter is classified into two groups porous or non-porous. In present study, 9 matrices were used *i.e.* paper, cardboard, foam, cloth, metal, hair, wood, soil and meat. into two groups porous or non-porous. In present study, 9 matrices were used *i.e.* paper, cardboard, foam, cloth, metal, hair, wood, soil and meat. These matrices are burned in two conditions *i.e.* a complete burning condition wherein each material is burned until it ceased to fire whereas in a partial burning condition halt the time of complete cease of fire for a particular time was selected to extinguish the fire with water.

Paper: Cellulose is the main content of the paper which is brownish in colour. Brownish tinch of the paper was removed

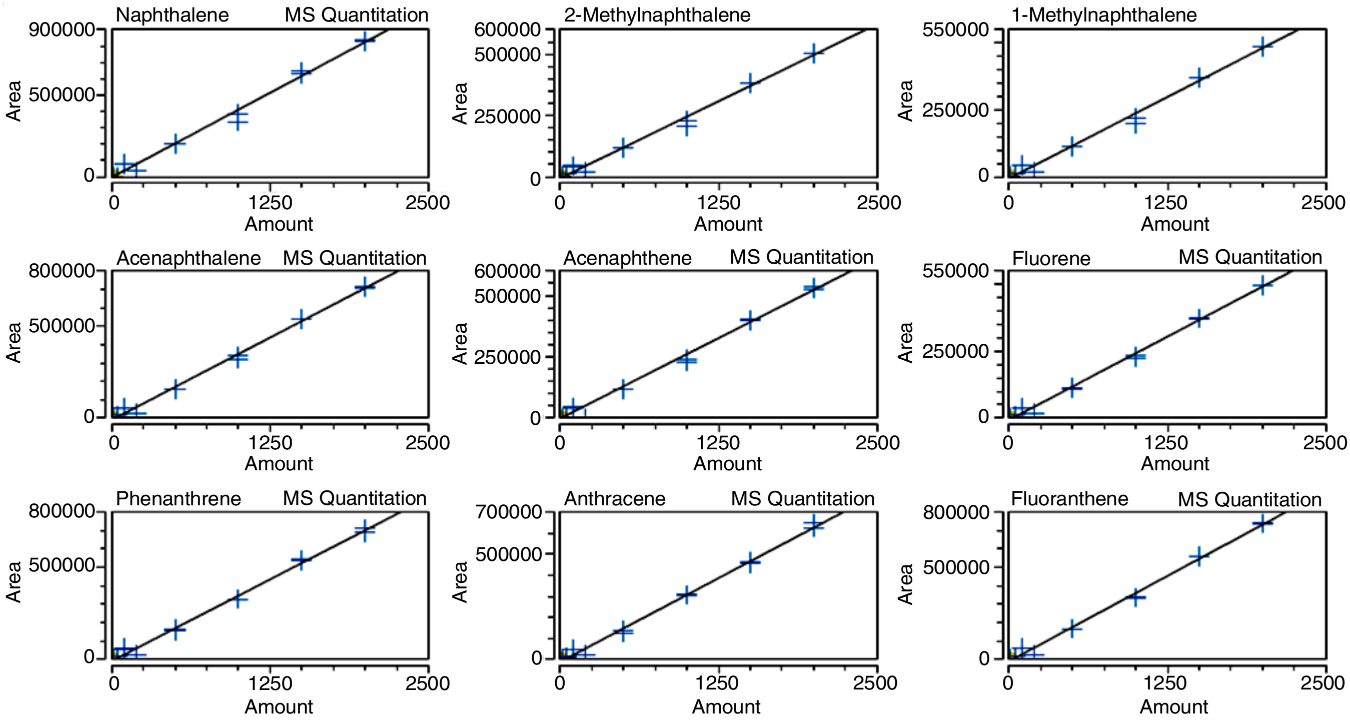

Fig. 1. Calibration graph of naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene and fluoranthene

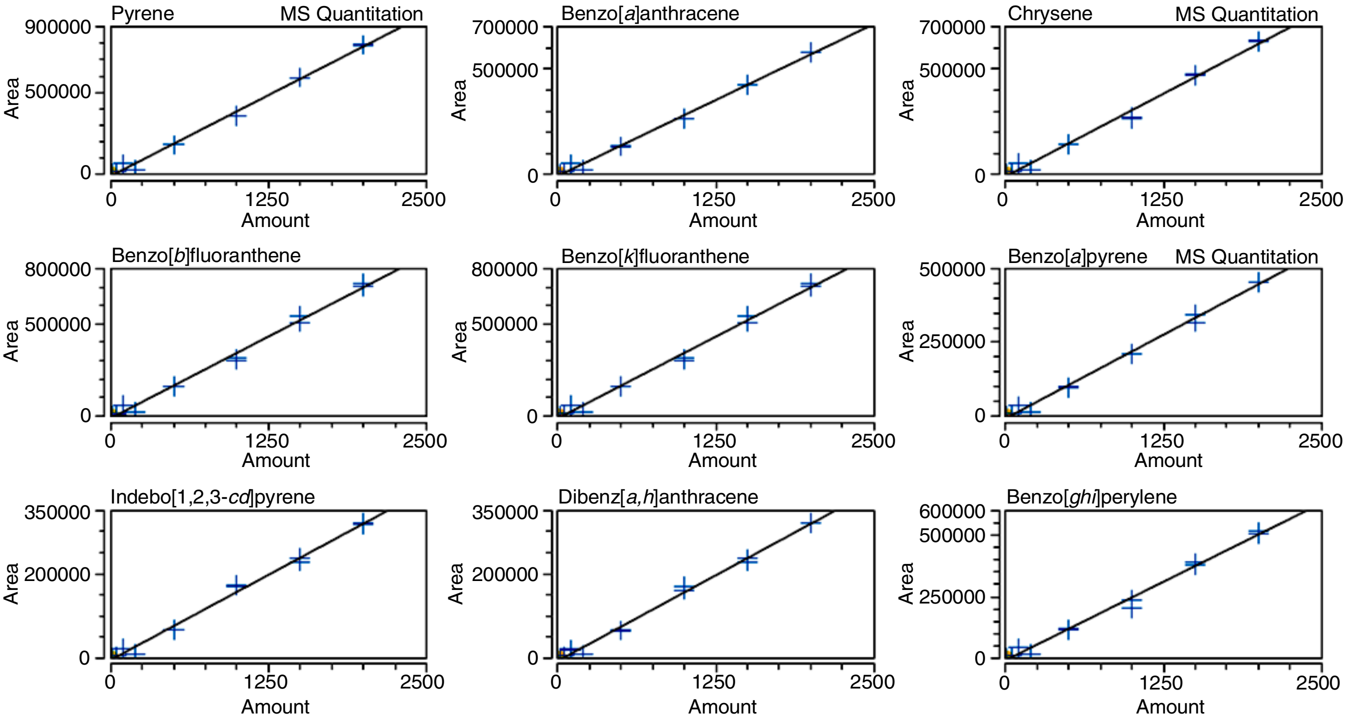

Fig. 2. Calibration graph of pyrene, benzo[*a*]anthracene, chrysene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene, indebo[1,2,3-*cd*]pyrene, dibenz[*a,h*]anthracene and benzo[*ghi*]perylene

through bleaching process [29]. In paper burned with gasoline in partially burned condition, the concentration of naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[*a*]anthracene, chrysene, benzo(*b*)fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene and benzo(*g,h,i*)perylene were found to be 1720.94, 778.18, 570.84, 715.64, 33.18, 349.77, 1227.34, 623.73, 532.05, 34.16, 137.20, 185.69, 70.01, 81.35, 158.34 and 84.44 µg mL^{-1} respectively. In completely burned condition it was found to be 91.26, 87.24, 71.68, 57.68, 10.05, 71.34, 278.41, 317.20, 130.27, 147.39, 44.42, 54.63, 42.42, 41.39, 50.88 and 52.27 µg mL^{-1}, respectively. In addition to that in completely burned conditions, dibenz[*a*,*h*]anthracene and indeno[1,2,3-*cd*]pyrene was also detected with concentration 47.39 and 42.54 µg mL^{-1}, respectively. Paper take less time to completely burned. As the temperature of burning increases, it also decreases the concentration of low molecular weight PAHs. Hence the concentration of napthalene, 1- and 2-methylnaphthalene were higher in partially burned condition as compared to completely burned paper sample. The chromatograms of 18 PAH compounds for partially and completely burned paper with gasoline is illustrated in Fig. 3 and 4, respectively.

Cardboard: Corrugated cardboard boxes are made up of unbleached brown Kraft paper. It was made by gluing one or more sheets of paper on one another [30]. The thickness of the corrugated boxes arEe more than normal craft paper which affect its burning time and temperature hence directly affect the formation of PAHs. In cardboard burned with gasoline in partially burned condition concentration of naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[*a*]anthracene, chrysene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene and benzo[*g*,*h*,*i*]perylene found to be 6993.41, 4981.46, 3245.73, 588.45, 97.28, 473.58, 1321.77, 736.16, 352.46, 449.65, 143.63, 127.83, 56.23, 60.36, 123.51 and 77.46 µg mL^{-1}, respectively. In completely burned condition, it was found to be 223.92, 111.91, 84.44, 66.84, 33.29, 80.01, 196.86, 49.37, 120.23, 124.56, 42.62, 51.20, 38.15, 37.11, 40.46 and 40.99 µg mL^{-1}, respectively. In addition to that in completely burned condition indeno[1,2,3-*cd*]pyrene is also detected with concentration 39.15 µg mL^{-1}. Bardboard is much harder than paper sample and time of burning and temperature and burning of cardborad is maximum as compared to paper, hence it consist of high concentration of PAHs as compared to paper sample.

Foam: In present study, expanded polyethylene (EPE) based foam is lightweight, durable and non-dusting flexible and elastic material which is easy to cut, wrap around, perforate or seal, with high impact resistance capacity, which is non-toxic and odourless. The extruder melts the solid plastic material, mixes with blowing agent, nucleating agent which reduces polymer density. At that stage different chemicals added in the extruder, which produces low and high density EPE sheets [31]. In foam sample burned with gasoline in partially burned condition concentration of naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[*a*]anthracene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene and benzo[*g*,*h*,*i*]perylene found to be 32088.15, 17958.02, 11420.40, 4420.78, 727.88, 1892.80, 4378.68, 75.21, 1084.79, 1204.93, 324.10, 89.71, 94.06, 290.14 and 137.63 µg mL^{-1}, respectively. In completely burned condition, it was found to be 3062.65, 2463.01, 1616.73, 544.65, 145.75, 430.13, 1068.22,

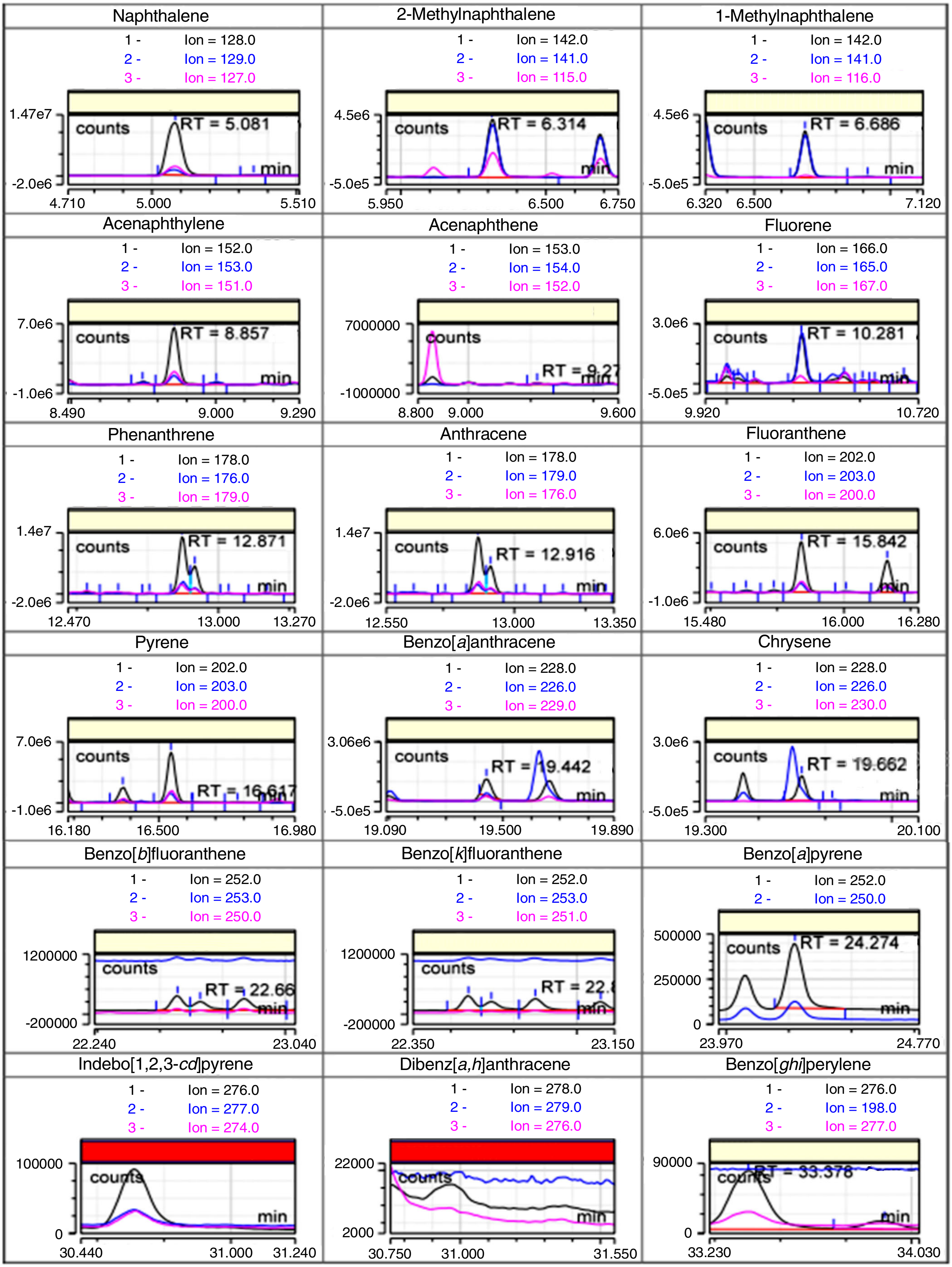

Fig. 3. GC-MS chromatogram of 18 PAHs for partially burned paper with gasoline

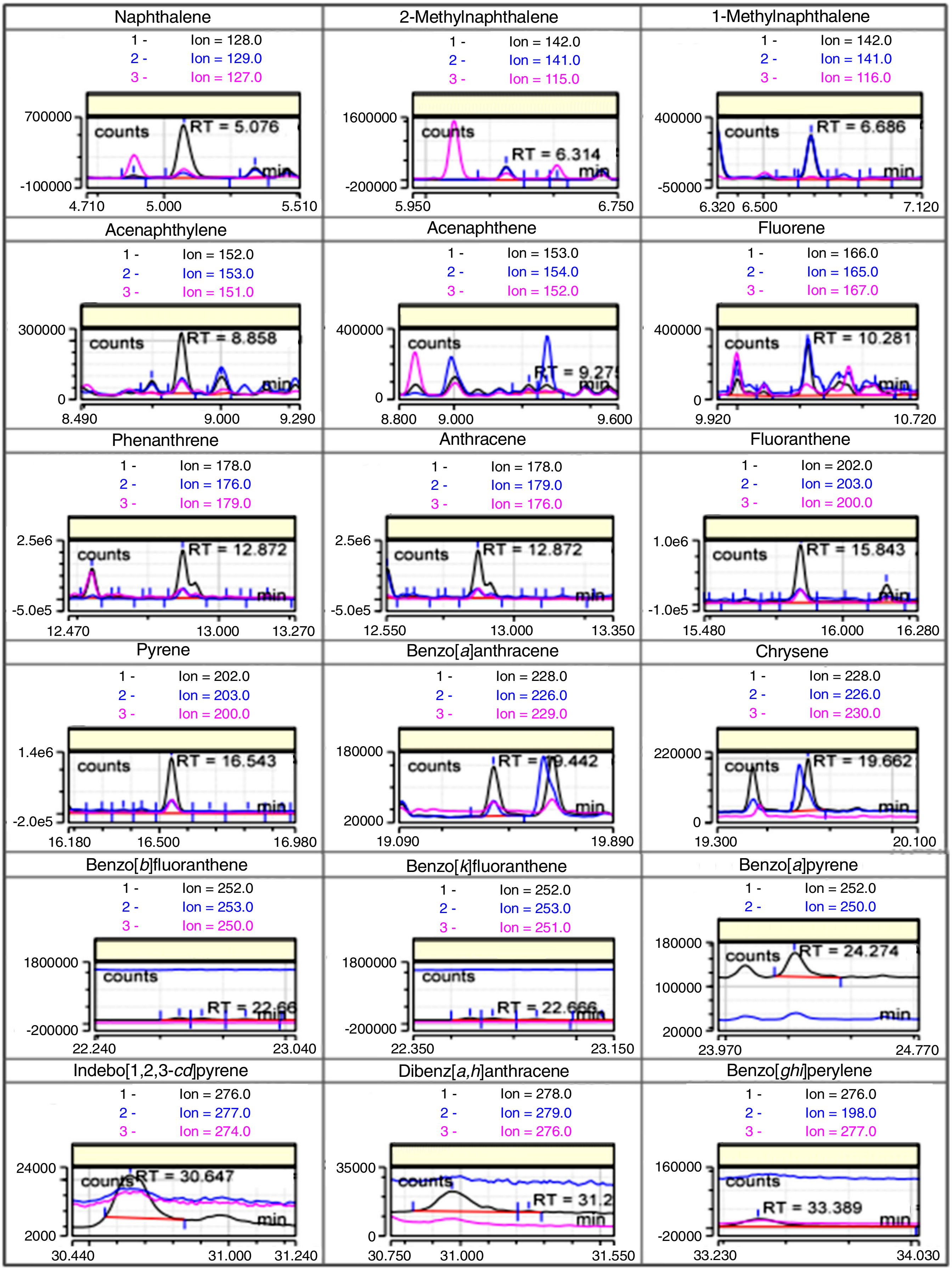

Fig. 4. GC-MS chromatogram of 18 PAHs for completely burned paper with gasoline

1068.22, 625.17, 302.73, 342.60, 134.90, 111.68, 55.72, 56.99, 120.13 and 72.55 µg mL^{-1}, respectively. In addition to that in completely burned condition chrysene and indeno[1,2,3-*cd*]-pyrene was also detected with concentration 111.68 and 59.31 µg mL^{-1}, respectively. Foam are made up of plastic material hence itself consist of PAHs and after burning it produces higher concentration of PAHs as compared to paper and cardboard. Similar study conducted by Yeo *et al.* [32] analyzed new and beached expanded polysterene sheets for the detection of 28 PAHs compounds. There were 16 different PAHs detected throughout both sheets, with varied concentrations that help in material identification.

Cloth: In present study white cotton fabric is used which is obtained from seedpod of cotton plant. Cloth as fire evidence found in house burning, human burning and industrial burning cases. In case of human burning cloth collected from the deceased person play crucial role in identification of ignitable liquid. Cloth sample burned with gasoline in partially burned condition, the concentration of naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo-[*a*]anthracene, chrysene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene and benzo[*g*,*h*,*i*]perylene were found to be 440.41, 272.75, 205.80, 254.18, 17.88, 181.71, 514.23, 189.70, 173.84, 185.10, 81.04, 92.87, 47.81, 50.49, 87.47 and 85.11 µg mL^{-1}, respectively. In completely burned condition, it was found to be 136.77, 138.03, 525.06, 46.33, 773.26, 2486.47, 822.34, 656.51, 600.61, 179.58, 215.29, 57.66, 63.39, 94.84 and 66.44 µg mL^{-1}, respectively. In addition to that in completely burned condition indeno[1,2,3-*cd*]pyrene was also detected with concentration 50.97 µg mL^{-1}. However, naphthalene was not detected in the completely burned condition. Cloth take maximum time of burning as compared to other hence most of the lower molecular weight PAHs removed in completely burned condition. Hence, the concentration of low concentration of lower molecular weight PAHs was found in completely burned condition.

Metal: In this study, steel box strapping clips were collected as a fire evidence in industrial fire cases. Metal is polished material and does not absorb any ignitable liquid. Metal burned with gasoline in partially burned condition, the concentration of naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[*a*]anthracene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene and benzo-[*g*,*h*,*i*]perylene were found to be 486.37, 886.92, 662.21, 485.15, 307.64, 1083.71, 5962.88, 153.66, 3394.13, 3643.99, 1071.04, 413.00, 438.87, 1376.35 and 674.06 µg mL^{-1}, respectively. Chrysene was not detected in the partially burned sample. In case of completely burned condition, it was found to be 156.04, 115.30, 99.01, 494.03, 38.12, 965.77, 3653.63, 2008.88, 1800.20, 1748.59, 379.02, 193.01, 192.08, 628.25 and 387.08 µg mL^{-1}, respectively. Since metal surface is a non-porous in nature, hence it burns with low concentration of PAHs.

Hair: In hair burned with gasoline in partially burned condition, the concentration of naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, acenaphthylene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[*a*]-anthracene, chrysene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene and benzo[*g*,*h*,*i*]perylene was found to be 709.93, 378.03, 249.82, 69.18, 107.13, 175.77, 115.47, 78.60, 104.47, 41.55, 47.39, 36.56, 35.89, 46.52 and 45.11 µg mL^{-1}, respectively. In completely burned condition, it was found to be 3617.31, 1985.26, 1255.86, 454.03, 35.09, 428.37, 716.63, 232.67, 262.21, 92.55, 85.69, 49.10, 48.06, 101.42 and 66.12 µg mL^{-1}, respectively. Acenaphthene was not detected in the partially burned sample however it was detected in completely burned sample with concentration of 423.80 µg mL^{-1}. Moreover, it was found that PAHs concentration is higher in completely burned condition as compared to partially burned sample.

Wood: In this study, teak hardwood block is used. Wood sample burned with gasoline in partially burned condition, the concentration of naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[*a*]anthracene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene and benzo[*g*,*h*,*i*]perylene was found to be 1610.14, 1953.75, 1427.91, 2069.73, 175.17, 1644.00, 4193.77, 100.15, 1735.88, 1694.08, 474.80, 254.76, 261.67, 759.08 and 103.79 µg mL^{-1}, respectively. In completely burned condition it was found to be 1460.59, 1264.81, 945.24, 344.85, 94.45, 296.93, 1040.49, 494.52, 662.28, 738.66, 296.39, 206.19, 216.19, 575.90 and 506.57 µg mL^{-1}, respectively. Moreover, chrysene was not detected both in partially and completely burned samples. Gustafson *et al.* [33] studied PAHs obtained from indoor wood burning in this anthracene, benzo(*ghi*)fluoranthene, chrysene, benzo[*a*]pyrene, benzo[*a*]anthracene, indeno[1,2,3-*cd*]pyrene and benzo(*ghi*)perylene was detected [33].

Soil: Soil as a fire evidence collected in case of house fire, industrial fire and wildfire *etc.* soil burned with gasoline in partially burned condition concentration of naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[*a*]anthracene, chrysene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene and benzo[*g*,*h*,*i*]perylene was found to be 9197.63, 4814.43, 3033.23, 271.26, 217.26, 316.59, 727.45, 535.39, 156.39, 203.34, 91.14, 78.27, 44.95, 47.45 and 35.27 µg mL^{-1}, respectively. In completely burned condition, it was found to be 6013.16, 3501.22, 2204.72, 147.02, 150.72, 370.91, 1612.45, 1802.81, 397.77, 354.33, 164.43, 150.46, 64.21, 72.34 and 82.38 µg mL^{-1}, respectively. Benzo-[*a*]pyrene detected in partially burned condition with 92.99 µg mL^{-1} however, it was absent in completely burned condition.

Meat: In this study, meat sample was used to resemble skin sample which is easily collected in the human burning sample. In meat burned with gasoline in partially burned condition concentration of naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[*a*]-anthracene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo-[*a*]pyrene and benzo[*g*,*h*,*i*]perylene was found to be 23458.69, 11164.79, 7265.27, 3937.76, 337.98, 2109.10, 4606.86, 87.16, 1518.52, 1537.45, 400.70, 171.78, 32.88, 559.26 and 298.89

μg mL^{-1}, respectively. In completely burned condition it was found to be 2150.57, 1041.83, 598.30, 151.75, 20.60,144.15, 372.86, 157.36, 156.77, 186.64, 65.05, 41.12, 40.08, 34.93 and 59.09 μg mL^{-1}, respectively. Similarly, chrysene was not detected in the partially burned sample, however, chrysene was detected in the completely burned sample with concentration 64.75 μg mL^{-1}.

Principal component analysis (PCA): In present study, XLSTAT software was used to perform PCA. PCA was obtained for both partial and complete burning condition data. Each PAH out of 18 PAHs understudy is considered as one-variable hence therefore there as 18 variables for each condition. For each variable minimum and maximum values were determined based on that mean value and standard deviation were calculated for each variable in both conditions. In partial burning condition based on the data set 8 principal components were obtained out of the first two factors F1 and F2 have the highest eigenvalue of 9.142 and 5.121, respectively and hence selected to obtain PCA. F1 and F2 gives 57.14% and 32% of information and combined give 89.14% of the information, which is the highest in number when compared with other factor combinations.

Biplot-1 represents the principal component analysis plot based on the F1 and F2 factors (Fig. 5a). In that 3P and 9P, *i.e.* foam and meat material consist of naphthalene, 1-methylnaphthalene, 2-methylnaphthalene, acenaphthylene, acenaphthene, fluorene and phenanthrene as a common source of gasoline as the ignitable source. The 5P and 7P *i.e.* metal and wood consist of pyrene, fluoranthene, benzo[*a*]anthracene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene and benzo[*g,h,i*]perylene common sources of gasoline as the ignitable source. 1P, 4P, 6P *i.e.* paper, cloth and hair consist of more prominently anthracene and chrysene. Similarly, biplot-2 represents principal component analysis based on F1 and F2 factor F1 and F2 gives 48.01% and 23.79% of information and combined gives 71.79% of the information (Fig. 5b). Material numbers 3C, 6C and 8C *i.e.* foam, hair and soil formed a group and consisted of naphthalene, 1-methylnaphthalene, 2-methylnaphthalene and chrysene. 1C, 2C and 9C *i.e.* paper, cardboard and meat sample consist of dibenzo[*a,h*]anthracene and indeno[1,2,3-*cd*]pyrene. The 5C and 7C *i.e.* metal and wood consist of fluoranthene, pyrene, benzo[*a*]pyrene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene and benzo[*g,h,i*]perylene. In complete burning condition anthracene, phenanthrene, acenaphthylene, acenaphthene, fluorene and benzo[*a*]anthracene does not correlate with any material. Hence, the partially burned materials give more information as compared to a completed burned materials.

Conclusion

In this work, gas chromatography-mass spectrometry (GC-MS) was found to be specific, accurate and sensitive analytical technique for identification of PAHs. Based on the above observations, it is concluded that the meat, hair, metal and soil sample gives more information about the source of accelerant accurately and the type of burned sample *i.e.* partial burned or complete burned does not affect the results of PAHs. It has been demonstrated in the literature that porous materials absorb as much as a possible accelerant and are thus more suitable for identification when compared to non-porous materials, but the current study found that metal materials are excellent for source identification. Evidence typically obtained in human burning instances consists of clothing, scene debris and samples of skin and hair, with the latter two being most useful for identifying the accelerant used in the fire. When a fire crime scene involves a large area then in this case soil sample is more suitable for the accelerant identification. Plastic material like polythene bags and the foam itself increases the concentration of PAHs after burning hence these type of samples are selected when a control sample is available. The type of cloth material used also affect the concentration of PAHs. Synthetic material increases concentration as compared to natural cloth like cotton. Time of burning affects the concentration of PAHs as a time of burning increases losses most of PAHs hence paper and cardboard take less time as compared to all other matrices for burning hence less information is revealed from paper and cardboard samples.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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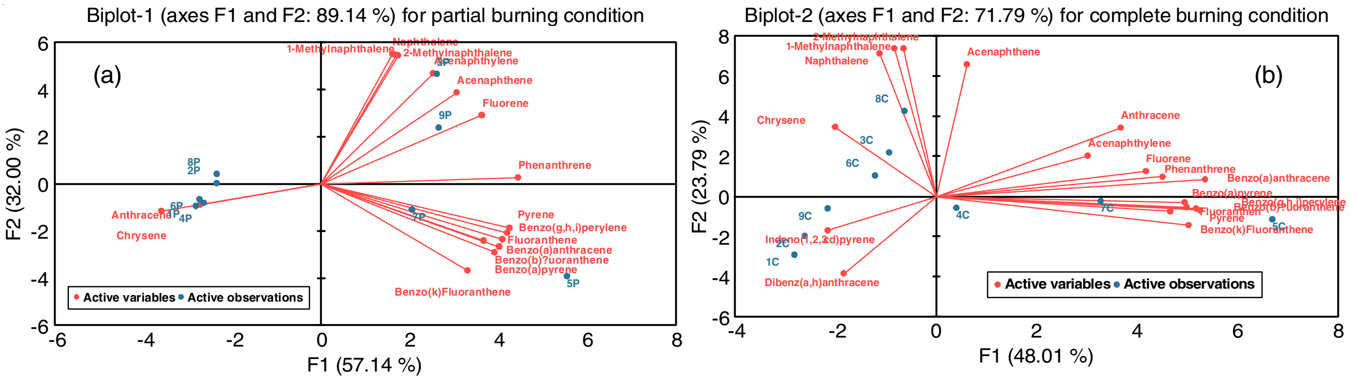

Fig. 5. Principal component analysis module for (a) all partially burned samples, (b) all completely burned samples

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