CHAPTER II

LITERATURE REVIEW

2.1 ARSON

2.1.1 Definition of Arson

The FBI defines arson as “any wilful or malicious burning or attempt to burn, with or without intend to defraud, a dwelling house, public building, motor vehicle or aircraft, personal property of another, etc.” (SIR 2009).

2.2 MOTIF

Arson or attempt to burning defines as crime to property or personal normally because of several motives (Cahill 2009). Approximately half of all arson fires are set by juveniles. The majority are motivated by insurance fraud. Others are committed to cover another crime, vandalism, revenge and also psychology factor (Bennett et al. 2007).

Besides that, childhood firesetters has been developed in the literature. Accidental firesetters are children under the age of eleven. These children have few problems socializing or expressing emotions or may simply be exploring fire.

2.2.1 Insurance fraud

The largest category of arson crimes are insurance fraud. The motif is clear; to get money fast on a business or property that is losing money. They will even have increased insurance premiums on the property not long before setting the fire. Others may remove expensive equipment by selling it separately to get more money. Normally the owner likely hires another individual to set a fire (Embar & Pass 2009).

2.2.2 Arson to cover another crime

This motif was committed in order to cover up another crime or to obliterate any evidence by individual. These crimes include murder, robbery and also destruction of the important documents (NFPA 2004). Burning after murder was intended to eliminate any evidences that may be found on the victims. In addition, identification of the victim will be more difficult due to the damage an exterior of the body.

2.2.3 Vandalism

Generally vandalism is set by juveniles. They set fires normally on public property such as educational facilities, abandoned buildings, vehicle, shrubbery and also bins provided by municipal council (Fisher & Lab 2010). Boredom and frustration among the youth encouraging them challenge their peers to do something more fun. In some cases, such challenge was done to be accepted as a member in the group (DeHaan 2002).

2.2.4 Revenge

Statistically, only a small number of arson fires are motivated by revenge. Revenge fires are usually set by deliberately burn on the individuals, institutions and also community. This occurred because the victims have an injustice experienced against him (NFPA 2004). Setting a revenge fire usually planned sudden fire or serial.

2.2.5 Psychology Factor

Mental illness that is often associated with arson is schizophrenia, pironamia and antisocial personality disorder. Pironamia is a disease controlled by impuls (Gannon & Pina 2010).

i) Piromania

Piromania caused by repeatedly present feeling to start a fire. Piromania considered as a treatment to pleasure, satisfaction, relief when committing the crime and perpetrators felt dazzled when see the fire (First & Tasman 2009).

ii) Schizophrenia

Schizophrenia is a mental illness which is suffered from hallucinations and delusion symptoms. Such symptoms can be interfered the ability to understand the situation around him. Previous study showed that, individuals suffering schizophrenia are more likely to commits arson (Anwar et al. 2009).

iii) Antisocial personality disorder

Individual who are suffering antisocial personality disorder have a different internal problem compared to normal people. They act like a hero to extinguish fire that triggered by their own (Kocsis 2002).

2.3 ACCELERANTS

Ignitable liquid were used as a fire booster is volatile. Accelerant was used to increase the intensity and spread of the fire. Petroleum-based fuels such as gasoline, kerosene and diesel are commonly used as accelerants in arson (Hupp, A. et al. 2008). In the arson investigation, accelerants detection is importance due to the presence of substance must be proven to be classified as arson (Smith, S.E. 2009).

Petroleum-based ignitable liquids are very easily available in Malaysia. In generally, Malaysia oil supplier such as Petronas, Shell, BHP, Caltex and Esso-Mobile are all over the country. This is easy for criminal to acquired ignitable liquid for the purpose of the intentionally burning without constraints of any party. Most of the arsonists were used petroleum-based accelerant such as gasoline, kerosene, and paint thinner because of their low cost and easy availability (Tan et al. 2000).

2.3.1 American Society for Testing and Material (ASTM)

In fire investigation, often fuel analysed from hydrocarbon. A guideline for the classification of ignitable liquid has been developed by ASTM as a reference to identify the accelerant found at the scene. The updated ignitable liquid classifications by ASTM are shown detail in Table 2.1 and Table 2.2 is a new system uses of two dimensional was defined more categories and each were divided into three subcategories except the petrol.

Table 2.1: Previous ASTM classification system of ignitable liquids

Class number	**Class name**	**Carbon range**	**Dominant component**
1	Light petroleum distillates (LPD)	$C_4 – C_8$	Alkanes
2	Gasoline	$C_4 – C_{12}$	Alkanes,Alkylbenzene, Naphtalene
3	Medium petroleum distillates (MPD)	$C_8 – C_{12}$	Alkanes, Alkylbenzene
4	Kerosene	$C_9 – C_{16}$	Alkanes,Alkylbenzene, Naphtalene
5	Heavy petroleum distillates (HPD)	$C_{10} – C_{23}$	Alkanes,Alkylbenzene, Naphtalene
0	Miscellaneous	Miscellaneous	Alkanes
0.1	Oxygenated solvents		Alkylbenzene
0.2	Isoparaffins		Alcohols
0.3	Normal Alkanes		Ketones
0.4	Aromatic solvents		Esther
0.5	Napthenic/paraffinic solvents		Terpene

Source: Stauffer & Lentini (2003)

Table 2.2: New ASTM classification system

Class	**Light (C_4-C_9)**	**Medium C_8-C_{13}**	**Heavy C_8-C_{20}**	**Alkanes**	**Cycloalkanes**	**Aromatics**	**Polynucleic Aromatic**
Gasoline	Fresh gasoline typically falls in range of C_4-C_{12}			Present, less abundant than aromatics	Present, less abundant than aromatics	Abundant	Present
Petroleum distillates	Petroleum ether, cigarette lighter fluids, camping fuels	Charcoal starters, paint thinners, dry cleaning solvents	Kerosene, diesel fuel, jet fuels, charcoal starters	Abundant, Gaussian distribution	Present, less abundant than alkanes	Present, less abundant than alkanes	Present (depending on boiling range0, less abundant than alkanes
Isoparaffinic products	Aviation gas, specialty solvents	Charcoal starters, some paint thinners, some copier toners	Commercial specialty solvents	Branched alkanes abundant, n-alkanes absent or strongly diminished	Absent	Absent	Absent
Aromatic products	Paints and varnish removers, automotive part cleaners, xylenes, toluene-based products	Automotive parts cleaners, specialty cleaning solvents, insecticide vehicles, fuels additives	Insecticide vehicles, industrial cleaning solvents	Absent	Absent	Abundant	Abundant (depending on boiling range)
Naphthenic paraffinic product	Cyclohexane based solvents/products	Charcoal starters, insecticide vehicles, lamp oils	Insecticide vehicles, lamp oils, industrial solvents	Branched alkanes abundant, n-alkanes absent or strongly diminished	Abundant	Absent	Absent
n-Alkanes products	Solvents, pentane, hexane, heptane	Candle oils, copier toners	Candle oils, carbonless forms, copier toners	Abundant	Absent	Absent	Absent
De-aromatic distillates	Camping fuels	Charcoal starters, paint thinners	Charcoal starters, odourless kerosene	Abundant, Gaussian distribution	Present, less abundant than alkanes	Absent or strongly diminished	Absent or strongly diminished
Oxygenated solvents	Alcohols, ketones, lacquer thinners, fuel additives, surface preparation solvents	Lacquer thinners, industrial solvents, metal cleaner/gloss removers		Composition may vary, presence of oxygenated organic compound			
Other-miscellaneous	Single component products, blended products, enamel reducers	Turpentine products, blended products, various specialty products	Blended products, various specialty products				

Source: Stauffer & Lentini (2003)

2.3.2 Petroleum-based Accelerants

Petroleum hydrocarbons are classified into three major groups based on their molecule structure of alkanes, alkenes and aromatic hydrocarbons. Alkanes or paraffin containing single carbon bonds which are a major component in petroleum products. Alkenes or olefins bearing double bond carbons and usually it's not a component of crude oil. It was formed during the filtration process in the manufacturing of commercial petroleum products. Aromatic hydrocarbons containing ring structure with conjugate carbon bonds. Therefore, it's have some unique features such as specific smell and toxic.

Most of the crude oil has a low boiling fraction such as gasoline, medium boiling fraction for diesel and high boiling fraction such as asphalt. Gasoline usually contains alkanes (C_4-C_{12}), alkenes (C_4-C_7), water soluble monochromatic, and additives. Middle distillate such as kerosene, diesel, and jet fuel typically contains alkanes (C_{10}-C_{24}), monochromatic, slightly water-soluble polynuclear aromatic hydrocarbons (PAH), metals and certain additives. A waste product such as diesel and motor oils typically contains alkanes (C_{20}-C_{78}), insoluble PAH, and metals like nickel and vanadium (Santi et al. 2006). Level of crude oil fraction and physical characteristic of petroleum distillation is shown details in Table 2.3 and 2.4.

Table 2.3: Level of crude oil fractions

Boiling point °C	Fraction	Uses
Below 20	Natural gas	Fuel
20 – 60	Petroleum ether	Solvent
60 – 100	Light naphthalene	Solvent
26 – 190	Petrol (gasoline)	Motor fuel
165 – 255	Paraffin (kerosene)	Heating fuel
180 – 340	Diesel	Motor fuel
Vacuum distillates	Heavy oil	Lubricants
Vacuum distillates	Grease	Lubricants
Vacuum distillates	Asfalt	Road paving (tar)

Source: De Vos, B.J. 2005

Table 2.4: Physical characteristic of petroleum distillation

Petroleum distillate	Boiling point °C	Torsion point °C	Ignition temperature °C
Kerosene	175-260	38-74	229
Gasoline	40-190	-43	257
Diesel	190-340	69	399
Jet fuel	N/A	150-230	260-371
Acetone	57	-20	465
Octane	126	13	220
Ether	35-60	-18	288
Turpentine spirits	135-175	35	253
Alcohol	78	13	365
White spirits	150-200	35	232

Source: Pert et al. 2006

2.3.3 Natural Gas

Natural gas consists of 85-95 mol% of methane (CH_4), while the rest is carbon dioxide (CO_2), nitrogen (N_2), and small amount of heavy hydrocarbons such as ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}) (Rhoderick, G. 2003; Esteves, I. et al. 2008). Burning a natural gas provides a safe, clean, efficient and free from sulphur, lead oxide, benzene and solid particles (Esteves, I. et al. 2008). The density of fuel gas is shown in details in Table 2.5 (DeHaan, J.D. 2002) and Table 2.6 show a normal gas ignition temperature (NFPA 1991).

Table 2.5: The density of fuel gas

Fuel gas	**Density**
Hydrogen	0.07
Methane	0.55
Acetylene	0.90
Carbon monoxide	0.97
Ethane	1.03
Propane	1.51
Butane	1.93
Acetone	2.00
Pentane	2.50
Hexane	3.00

Source: Kirk’s Fire Investigation 2002

Table 2.6: Normal gas ignition temperature

	Ignition Temperature (minimum)	
Fuel	**°C**	**F**
Natural gas	482-632	900-1,170
Propane	493-604	920-1,120
Butane	482-538	900-1,000
Acetylene	305	581
Hydrogen	500	932
Ammonia	651	1,204
Carbon monoxide	609	1,128
Ethylene	490	914
Ethylene oxide	429	804

Source: Fire Protection Handbook 1991

2.3.4 Ether (Petroleum)

Petroleum ether is mixed of colourless liquid alkanes and generally used as a solvent. Petroleum ether has lower boiling point between 35°C-38°C and contains the main component of pentane and hexane (Nielsen 2003). GC-MS is a suitable instrument to analyse compounds and compositions in petroleum ether (Ding et al. 2010).

2.3.5 Gasoline (Petrol)

Gasoline is a complex mixture of volatile flammable liquid hydrocarbon, mainly paraffinic, naphthenic, olefinic and aromatic. The composition of gasoline varies, depending on the type of crude oil from which it is originated and the type of processing undergone by the various refinery streams from which it is blended (Perez Pavon, J.L. et al. 2006).

Gasoline commonly used as accelerants in arson (Hupp, A. et al. 2008). Gasoline is usually characterized by the abundant and specific pattern of aromatics with a low level of aliphatics (Stauffer & Lentini 2003). Therefore, gasoline is easily volatile and explosive vapour easily explodes. Pure gasoline has a distinctive pattern of chromatograms and easily identified. Even though, it has higher rate of evaporates, makes their identification is difficult and often mistake as white spirits (Pert et al. 2006).

2.3.6 Kerosene

Kerosene is second accelerants are often used after gasoline. Kerosene contains one of the important fuels for heating oil and jet fuel. Chemically kerosene contains a mixture of aromatics and aliphatics complexes hydrocarbon with carbon numbers between C_9-C_{16}. The boiling point of kerosene is between 145°C to 300°C. The chemical composition of the kerosene depending where it is processed (Gómez-Carracedo et al. 2003). However, compared to gasoline that exclusively used for motor fuel, kerosene can be found in household products such as thinner, lighter and insecticide spray.

2.3.7 Diesel

Diesel contains paraffinic hydrocarbons with low sulphur content. Diesel is less volatile and more complex in terms of the chemical compared to gasoline. It is petroleum distillates with a boiling point at range 125-400°C. Components present in diesel including alkanes C_{10}-C_{22}, and aromatic benzene and also naphthalene-based (Hupp et al. 2008). Chromatograms of diesel have eight peaks that resemble characteristic of kerosene even with different ratios. Due to the high of boiling point limits, precaution should be taken during analysis to avoid losing of high boiling components. If a loss occurs, the resulting chromatograms resemble those obtained from evaporated kerosene. However a clear difference can be observed (Kaneko et al. 2008).

2.4 LABORATORY ANALYSIS

A variety of laboratory techniques are available for the analysis of hydrocarbons, in particular, gasoline. These techniques include gas chromatography (GC), gas chromatography-mass spectrometry (GCMS), high-performance liquid chromatography (HPLC), infrared spectroscopy (IR) and isotope ratio mass spectrometry (GCIRMS). The first analytical tool used by forensic scientist is often the GC, in particular, a GC equipped with a flame-ionization detector (GC-FID) (Oudjik, G. 2005). At the same time, statistical and chemometric method can be used to group fuels samples based on chemical similarities by statistically quantifying the pattern matching from chromatograms (Hupp, A. et al. 2008).

2.4.1 Sample Preparation

Gasoline is easily volatile compound, thus precaution need to be taken during the preparation of samples. Simple method commonly used is to extract gasoline samples using solvent such as methylene chloride or hexane in a certain ratio. Other extraction method can be used is Solid Phase Microextraction (SPME). SPME was developed in 1989 and is applied to a wide range of different kinds of analysis. SPME method has been shown to present an interesting sensitivity and rapidity. In addition, it is a completely non-destructive technique (Stauffer & Lentini 2003).

2.4.2 Chromatographic Analysis

Apart from the volatile, petroleum-based accelerants is a complex mixture consisting of alkanes, cycloalkanes and aromatic hydrocarbons. Therefore, gas chromatography is the most common analysis method used in forensic science for screening or for the purpose of identification. Gas chromatography separates the components in the sample based on the boiling point. At first application in the GC analysis of petrol, compact band system is matched with FID. However, progress in this field has been achieved since capillary band system was used by reason of resolution and higher sensitivity, although the capacity of the samples has been reduced. The second change is the replacement of the FID with mass spectrometer (MS) (Dolan 2003; Santi et al. 2006).

Identification and characterization of petroleum fuels can be performed using gas chromatography-mass spectrometry (GC-MS) (Hupp, A. et al. 2008). The use of GC-MS preferred because it can provide structural information of detected components molecule. A single peak in the total ion chromatogram can be separated and identified of both retention time and mass spectrum. Alternatively, extracted ion chromatogram also produced to provide a profile of a particular group of compounds (Tan et al. 2000).

2.5 INTERPRETATION OF RESULT

The presence of a component in the accelerants can close to the presence of a second accelerants component, especially when the quantity present vastly different. These affect the interpretation of GC-MS data. For example, the presence of aromatic hydrocarbons in gasoline can be close by paraffin in flammable liquid. Group of petroleum products are different. It is a mixture of large amounts and cannot be classified accurately in certain ranges (McCurdy et al. 2001).

2.5.1 Pattern recognition

In this context, the GC-MS chromatograms visually compared with known standard chromatogram by pattern matching or comparison with mass spectra database. Identification of petroleum products by visual inspection based on chromatographic data is time consuming and tends to misinterpretation. Although the matching is made by experience analysts, the resulting interpretations still contains subjective elements. The relationship between definitive samples can be achieved by mathematical procedure which is statistical comparison chromatograms. Statistical techniques such as principle component analysis has proven to be used to classify samples of fuel by quantify the statistical pattern matching and at the same time, based on chemical similarities (Hupp, A. et al. 2008).

2.5.2 Multivariate Statistical Analysis

Multivariate statistical techniques offer powerful tools in interpreting complex data. Principle component analysis (PCA) is significant technique for dealing with complex data interpretation. PCA relies on the linear transformation of the original set of measurements into a substantially smaller set of uncorrelated variables while retaining as much of information present in the original data set as possible. It gives a geometrical visualization of results in a lower dimensions space. PCA has been successfully applied to interpret complex data in a number of studying areas, such as design and characterization of chromatographic systems, sensors, environmental chemistry, food, and other industrial applications. This technique was successfully used to classify accelerants (Tan et al. 2000)

2.5.3 Determination of chemical fingerprints

Chemical fingerprint is a unique combination of analytical results from the specific techniques to identify specific compound in samples. Chemical fingerprint analyses based on GC elements pattern matching and identify special criteria such as dyes and additives or based on the relative ratio or certain elements. Accelerants have a chemical profile or fingerprint of certain volatile organic compounds. Although, this chemical fingerprint may change after burned, but most still have certain pattern that not affected by fire (Whyte et al. 2007).