A STUDY OF GASEOUS PRODUCTS OF MINERAL BASED INTUMESCENT FIRE RETARDANT COATING IN STRUCTURAL APPLICATION

by

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CERTIFICATION OF APPROVAL

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Department of Mechanical Engineering
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Approved:

_____

Assoc. Prof Dr. Faiz Ahmad
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

September 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ZAIFUL IQMAL BIN ZOHARI

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ACKNOWLEDGEMENT

First of all, I would like to express my deepest gratitude to almighty Allah, the Most Merciful and Compassionate for blessing me strength, health and willingness to prevail and finish this project.

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A very special note of appreciation goes to my lovely family for their constant help, encouragement and supports throughout the period of performing this project. I would like to express my gratefulness to Brillianto Brioann Boni and other mechanical engineering colleagues for contributing and sharing ideas throughout the project been done in UTP.

ABSTRACT

This project presents the study of the gaseous products of mineral fillers based intumescent fire retardant coatings in order to develop the inorganic fillers based intumescent fire retardant coatings. The coatings were formulated using ammonium polyphosphate (APP) as acid source, expandable graphite (EG) as carbon source, melamine as blowing agent, zinc borate as additives and epoxy as a binder. The different types of fillers such as aluminum trihydrate (ATH), alumina and talc were used in the intumescent fire retardant coatings formulation. This coating was coated onto steel substrate and there were 6 samples (0 %, 1%, 2%, 3%, 4%, and 5%) of fillers composition were prepared. After the curing period, the coating was tested using Gas Chromatography Mass Spectrometry (GCMS) in order to characterize the gaseous products after decomposition. There was presence of the organic compounds as the gaseous products of the samples such as benzyl alcohol. The higher percentage of mineral fillers in the formulation gave off less concentration of the gaseous products and more environmental friendly. The comparison has been made between the highest percentage of mineral filler and study shows that ATH 5% is the best to be used among the mineral fillers. The samples were then tested in furnace chamber at 450^{o}C. The chemical composition of residual char was determined using the X-ray Diffraction (XRD). There were presences of the boron oxide, graphite and boron phosphate which were stable at high temperature and helped to reduce the heat flow to the structural.

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CHAPTER 1: INTRODUCTION

1.1 Background of study

In recent decades, the frequent accidents caused by damage of structure in fire have reminded people of the risk of fire in some industrial buildings and homes. Statistics show that generally between 10 and 20 fire deaths per 1,000,000 inhabitants are reported in the major industrial countries of the world [1]. Most of the cases occur in residential buildings and the victims are least able to escape in the event of a fire and trapped with the toxicity gas such as Carbon Monoxide (CO). Thus, some efficient protective ways such as application of fire retardant coatings have been used to protect steel structure or any other materials such as polymers, textiles and woods in a fire. Intumescent fire retardant acts both by preventing the initial start of fire and by delaying the spread of fire, thus can increase the escape time during the event of fire. The coating is made up of three active ingredients which are an acid source, a carbon source and a blowing agent [2]. The ammonium polyphosphate (APP), expandable graphite (EG) and melamine (MEL) is a widely used system [2]. The coating swells as a result of heat exposure, thus increasing in volume, and decreasing in density [3]. Upon heating, the three active ingredients and the binder swell and form an intumescent char layer.

However, there is concern about the presence of the fire retardant either it contributes in increasing the toxicity in the smoke fire or not. This matter has to be considered since it can lead to the deaths of the trapped victims and also to the damages of environment.

1.2 Problem statement

The reaction of the fillers with the intumescent coating can improve the performances of the coatings. However, the common coating nowadays is brominated based flame retardants (BFR) and this coating can harm the victims as it releases the bromine gas. This bromine gas is known for its toxicological behavior towards human being and environment. It can cause malfunctioning of the nervous system and disturbances in genetic materials if been inhaled by people or victims of the fire occasion and immediately can lead to rapid risk of death. So it is not practicable to use the filler that can contribute to the increment of toxic gases in fire occasion.

The dangerous of using the BFR has led recent interest in using the organic compounds as the fillers for the coatings in order to reduce the emission of the hazard gases. The gaseous products from effects of the mineral fillers like ATH, Alumina and Talc when react with the APP-EG-MEL coatings have to be characterized in order to prove either the emission gaseous are toxic like the BFR does.

1.3 Objective

The objective is to help developing the minerals based intumescent fire retardant coating. This can be done based on the study of the characterization of gaseous products of intumescent coating which are from reaction of ATH, Alumina and Talc with the APP-PER-MEL coating.

1.4 Scope of study

The scope of study will consists of a few parts which are:

- Variety of fillers composition (ATH, Alumina, Talc)
- Pyrolysis in Gas Chromatography Mass Spectrometry (GCMS)
- Furnace Test for char expansion
- X-ray Diffraction Technique (XRD)

CHAPTER 2: LITERATURE REVIEW

2.1 Intumescent coating

Significantly the intumescent flame retardant coating is one of the most efficient and convenient way to protect materials such as metals, polymers, textiles and woods against fire [4]. An intumescent flame retardant coating is made up of intumescent flame retardant (IFR) system, binder and fillers. The intumescent flame retardant (IFR) system is composed of an acid source (ammonium polyphosphate-APP), carbon source (expandable graphite-EG) and a blowing agent (melamine- MEL) [4]. The three active ingredients and the binder swell and form an intumescent char layer and protect the base structure from the rapid increase of temperature upon heating at elevated temperature. There are several advantages of using the intumescent coating which are protecting any materials from being destroyed in fire, provide steel structures with corrosion protection and a strong decorative element if required [5]. Intumescent coating is designed to perform under severe conditions and to maintain the base structure integrity for one up to three hours when the temperature of the surroundings is exposing to temperature above 500^{o}C [6]. Besides, the intumescent coating also does not modify the intrinsic properties of the material such as the mechanical properties.

The resin which contains active ingredients will react in a fire at temperature around 250^{o}C to form a thermally insulating char [5, 6]. Basically the char can be expanded up to 50 times of the original coating thickness. The char reduces the rate of heating of the steel or other materials and thus prolongs its load bearing capacity. As the temperature rises, the binder begins to melt and the blowing agent liberates gases causing a controlled expansion. In the meantime, there is degradation of the carbon source and fusions of the inorganic reinforcing materials which are ATH, Alumina and Talc, resulting in char solidification [5, 6].

Ammonium Polyphosphate (APP) is an inorganic salt of polyphosphoric acid and ammonia containing both chains and possibly branching [7]. Its chemical formula is $[NH_4\ PO_3]_n$ which shows that each monomer consists of an orthophosphate radical of a phosphorus atom with three oxygen and one negative charge. This negative

charge has been neutralized by an ammonium cation leaving two bonds free to polymerize [7].

Expandable graphite (EG) is prepared from flake graphite by treatment with strong acids like sulphuric or nitric acid [8]. The acid is trapped in the crystal layers of the graphite. When it is heated, the graphite starts to expand up to several 100 cm^3 per gram and forms a protective layer for the polymer [8]. EG is commonly used in plastics, rubber coatings, textiles and polymeric foams. In intumescent coating, the EG should be used with other synergy agent like APP or zinc borate to get perfect flame retardancy [8]. When the EG react with the APP in intumescent coating, they yields the mineral acid and ammonia gas to the surrounding.

Melamine is an organic base and a trimer of cyanamide with a 1, 3, 5-triazine skeleton [9]. It consists of 66% nitrogen by mass. When mix with resins, melamine can posses fire retardant properties due to the release of nitrogen gas when it is burned or charred [9].

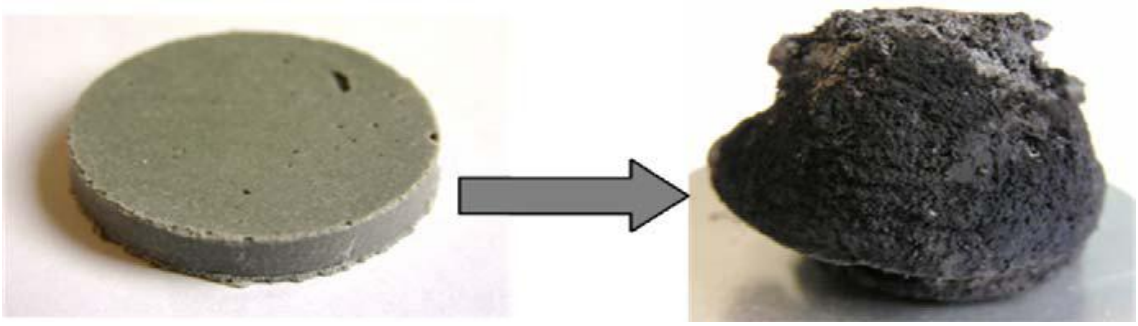

Figure 1: Swelling of an intumescent coating

2.2 Reactions of mineral fillers towards intumescent coating

Nowadays, there is a widespread of using the mineral fillers in order to replace the brominated flame retardants. This non-combustible fillers can reduce the flammability of a polymer by reducing the total amount of fuel, the rate of diffusion of oxygen into, and fuel from, the polymer bulk while can increase the heat capacity, thermal conductivity reflectivity and emissivity [10]. In addition, certain inorganic materials decompose endothermic ally with the release of inert gases or vapors, thus enhancing the effectiveness of fire retardant effect. Generally, the mineral fillers have three fire retardant effects which are [10]:

1. Endothermic decomposition, absorbing heat and therefore keeping the surrounding polymer cooler [10].
2. Production of inert diluents gases. The flaming reactions need a sufficient concentration of free radicals to be self-sustaining. If this concentration falls by the release of water or carbon dioxide, so the flame extinction will occur [10].
3. Accumulation of an inert layer on the surface of the decomposing polymer can shield the surface from incoming radiation. It also can act as a barrier to oxygen reaching the fuel, flammable pyrolysis products reaching the gas phase and radiant hear reaching the polymer [10].

For example, the aluminum hydroxide ($Al(OH)_3$) or known as alumina trihydrate (ATH) in fire retardant will decompose into alumina (Al_2O_3) with the release of water [10]. It will break down endothermic ally and forms water vapor, diluting the radicals in the flame, whiles the residue of alumina builds up to form a protective layer [10].

$$2Al(OH)_3\,(s) \xrightarrow{180-200\,^{\circ}C} Al_2O_3\,(s) + 3H_2O\,(g)\ \Delta h = +1.3KJ\ Kg^{-1}$$

For the other inorganic fillers like talc or chalk (calcium carbonate), they are not the flame retardants in common sense. However, by diluting in the combustible polymer they will reduce its flammability and fire load [3].

2.3 The Decomposition of pyrolysis

Pyrolysis is a process of thermo chemical decomposition of organic material at elevated temperatures without the participation of oxygen [11]. It is commonly involves the simultaneous change of chemical composition and physical phase, and is irreversible as well [11]. Pyrolysis is most used for organic materials and one of the processes involved is charring. The pyrolysis of organic substances produces gas and liquid products and leaves a solid residue richer in carbon content known as char [11, 12]. For the extreme pyrolysis, it will leave mostly carbon as the residue and is called carbonization [11, 12].

In general, pyrolysis-gas chromatography- mass spectroscopy (GC-MS) is employed in order to investigate decomposition processes and decomposed products of flame retardant [12].

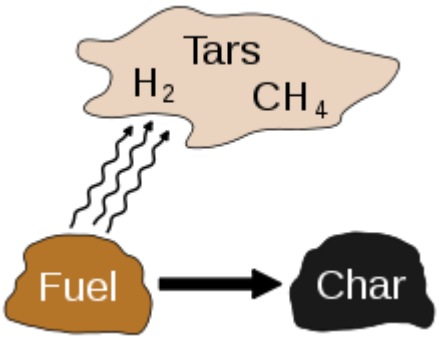

Figure 2: Simplified depiction of pyrolysis chemistry

CHAPTER 3: METHODOLOGY

3.1 Project flow chart

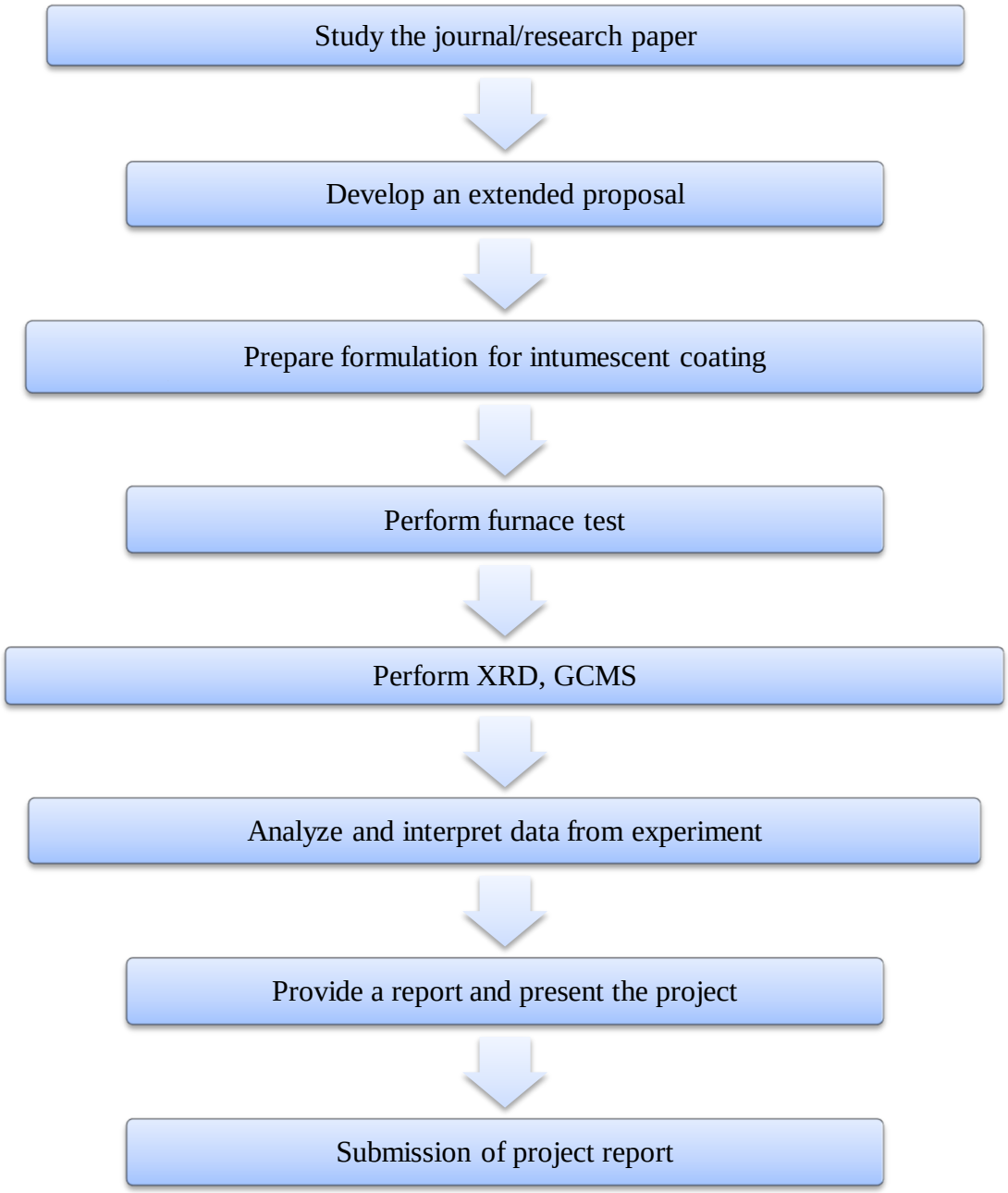

Figure 3: Project flow chart

3.2 Experiment overview

The project is started with the preparation of intumescent formulation. 16 formulations have been prepared with five for ATH, five for Alumina, and five for Talc and one without the filler. Each formulation has been coated into substrate steel. Ingredients of IFR that have been used are Ammonium Polyphosphate (APP), Expandable Graphite (EG), Melamine (MEL), zinc borate (ZB), Bisphenol-A (BPA) as the epoxy and TETA ad the hardener.

Table shown below is the portion of ingredients in the formulation.

Table 1: Formulation of ingredients without filler

Sample No	Components (wt %)					
	BPA	TETA	APP	EG	MEL	ZB
1a	44.44	22.22	11.11	5.56	5.56	11.11

Table 2: Formulation of ingredients with Alumina filler

Sample No	Components (wt %)						
	BPA	TETA	APP	EG	MEL	ZB	Filler (Alumina)
1b	43.94	21.72	11.11	5.56	5.56	11.11	1
2b	43.44	21.22	11.11	5.56	5.56	11.11	2
3b	42.94	20.72	11.11	5.56	5.56	11.11	3
4b	42.44	20.22	11.11	5.56	5.56	11.11	4
5b	41.94	19.72	11.11	5.56	5.56	11.11	5

Table 3: Formulation of ingredients with ATH filler

Sample No	Components (wt %)						
	BPA	TETA	APP	EG	MEL	ZB	Filler (ATH)
1c	43.94	21.72	11.11	5.56	5.56	11.11	1
2c	43.44	21.22	11.11	5.56	5.56	11.11	2
3c	42.94	20.72	11.11	5.56	5.56	11.11	3
4c	42.44	20.22	11.11	5.56	5.56	11.11	4
5c	41.94	19.72	11.11	5.56	5.56	11.11	5

Table 4: Formulation of ingredients with Talc filler

Sample No	Components (wt %)						
	BPA	TETA	APP	EG	MEL	ZB	Filler (Talc)
1d	43.94	21.72	11.11	5.56	5.56	11.11	1
2d	43.44	21.22	11.11	5.56	5.56	11.11	2
3d	42.94	20.72	11.11	5.56	5.56	11.11	3
4d	42.44	20.22	11.11	5.56	5.56	11.11	4
5d	41.94	19.72	11.11	5.56	5.56	11.11	5

After that, the coatings have undergone the furnace test where the coating samples being burned in the furnace.

The residual char of coating after heating undergo the X-ray Diffraction Technique (XRD) to know the composition. Meanwhile, the residue of the coating samples have to undergo the GCMS to study the decomposition processes involved and the products of the decomposition.

3.3 Formulation preparation process

The process was started with weighing the APP, Melamine, Zinc Borate and mineral fillers respectively according to the formulation potion. Then, the substances were mixed together and the mixture powder was grinded for one minute in Rocklabs grinder. Then, Expandable Graphite was weighed and added into the mixture. The epoxy and hardener was prepared according to the formulation portion and then poured into the mixture. The blend was mixed and stirred using mixer until completely mixed. The coating was applied onto the steel substrate with size 5cm x 5 cm and 10cm x 10cm. The sample is left to undergo curing at room temperature for about 2 days.

Figure 4: The coated steel substrate

3.4 Pyrolysis- GCMS test

After the samples had dried completely, the residues of the coating at the edges of the samples had been cut off and grinded until it become powder. After that, the powder of the coating had been sent to the Gas Chromatography Mass Spectrometry (GCMS) laboratory to undergo the GCMS test using a PYRO-CHEM WILKS pyrolyser, Hewlett Packard 5890 Series II gas chromatograph and TRIO 1000 mass spectrometer. The sample with weight of 10 mg was placed in the pyrolyser. The pyrolysis process was carried out at 25^{o}C to 800^{o}C in 10 sec. Then the pyrolysis products in the gas phase were injected into ion detector column to characterize the gaseous products.

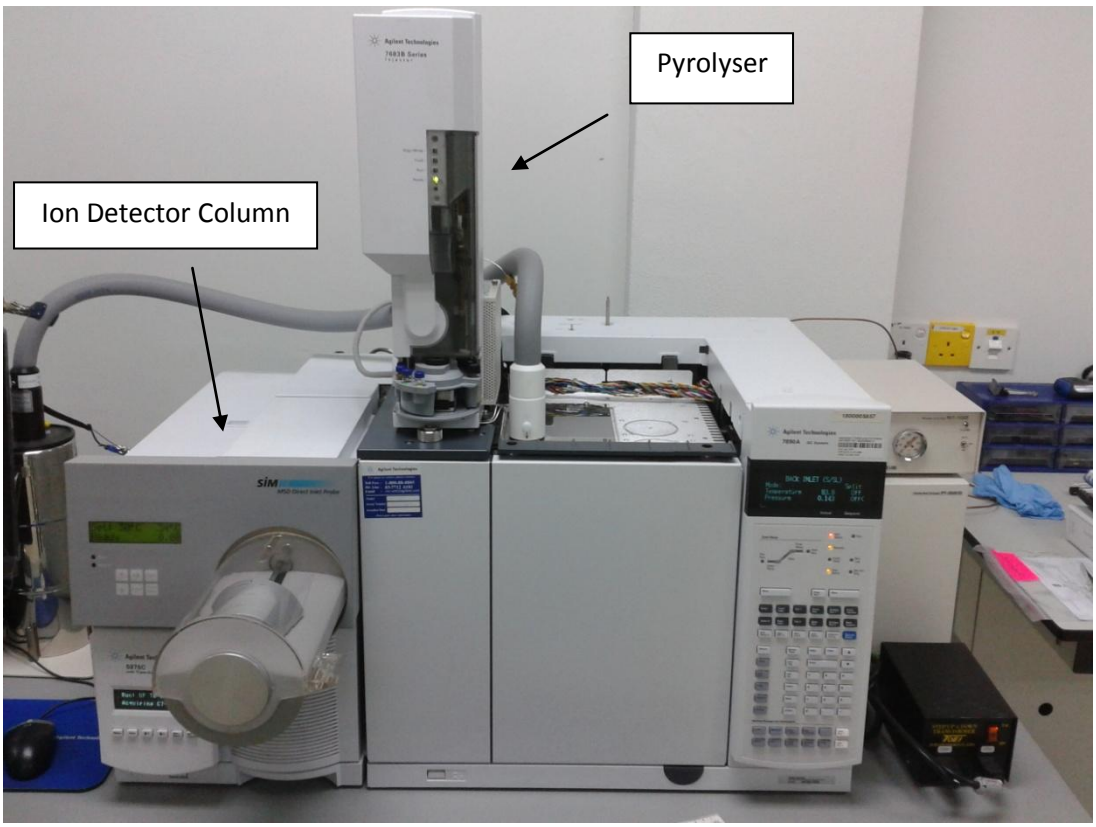

Figure 5: The Gas Chromatography Mass Spectrometry Machine

3.5 Furnace test

The samples had been undergone the furnace test inside the furnace chamber. The samples had been left approximately two hours during this test. The chamber had been set with temperature of 450^{o}C to burn the samples. There were 3 phases of this process. For the phase 1, the temperature was rising about 30 minutes to reach 450^{o}C. Then the process proceeded to the phase 2 which was the dwell of the temperature for about 30 minutes in order to burn the samples with perfect. The last phase was the decreasing of the temperature to the initial back which takes about 50 minutes for the chamber to cool down the sample to avoid cracking of char.

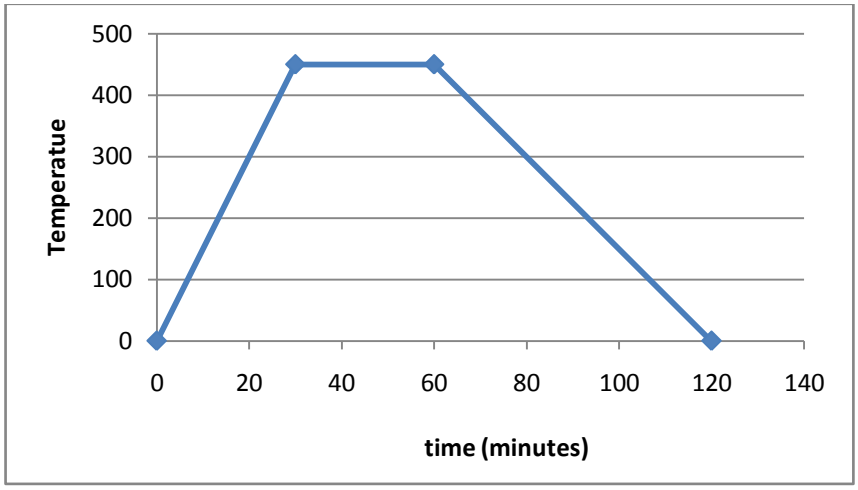

Figure 6: Temperature vs. Time Plot for sample burnt in furnace

Figure7: Furnace chamber

3.6 X-Ray diffraction test

XRD was used to study the composition of residual char of the intumescent fire retardant coating produced at 450^{o}C. XRD measurements were performed on a Bruker AXS D8 Advanced Diffractometer using Cu Kα radiation and a nickel filter (k= 0.150595nm) in the range of 10 <2θ< 90.

Figure 8: Residual char expansion

3.7 Project Gantt chart

Table 5: Project Gantt Chart for FYP I

No.	Details	Weeks													
		1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Consolidation of FYP Topics															
2	Topic assignments to students															
3	Research for the topic assigned															
3	Preparation for Extended Proposal															
4	Submission of Extended Proposal															
5	Research for the formulation of intumescent coating															
6	Preparation for Proposal Defence															
7	Proposal Defence															
8	Preparation for Interim Report															
9	Submission of Interim draft Report															
10	Submission of Interim Report															

MID SEMESTER BREAK

Project Activity

Key Milestone

Table 6: Project Gantt chart for FYP II

No.	Details	Weeks														
		1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Conducting the Furnace Test	■	■	■	■												
2	Conducting the GCMS			■	■	■	■	■		■							
3	Conducting the XRD										■	■	■				
3	Submission of progress report									⬭							
4	Analyze results of experiments												■	■			
5	Pre-EDX												■				
6	Submission of Draft Report													⬭			
7	Submission of Dissertation (soft bound)														⬭		
8	Submission of Technical Paper														⬭		
9	Oral Presentation															⬭	
10	Submission of Project Dissertation (hard bound)																⬭

MID SEMESTER BREAK

■ Project Activity

⬭ Key Milestone

CHAPTER 4: RESULT AND DISCUSSION

4.1 GCMS test results

WITHOUT FILLER

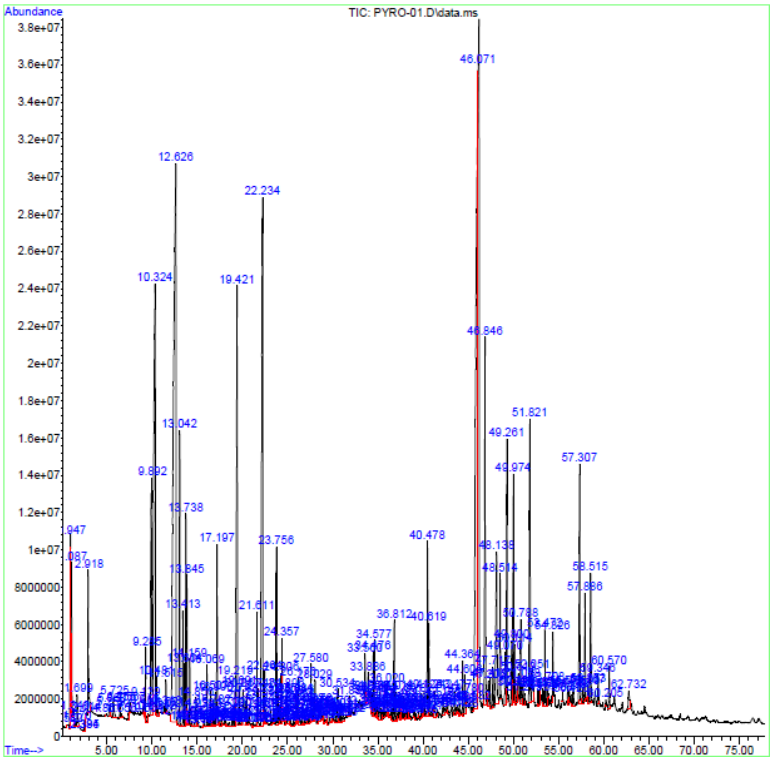

Figure 9: Graph of formulation no 1a

Retention time (min)	ID	Quality
46.071	Phenol, 4,4'-(1-methylethylidene)bis-	98
	Phenol, 2,4'-isopropylidenedi	87
	Phenol, 4,4'-(1-methylethylidene)bis-	81

Table 7: Gaseous products of formulation no 1a

Figure 9 shows the graph of no. of existing peaks for gaseous produced versus the retention time for formulation no 1a. The dominant gaseous product is phenol, 4, 4'-(1-methylethylidene) bis-.

ALUMINA

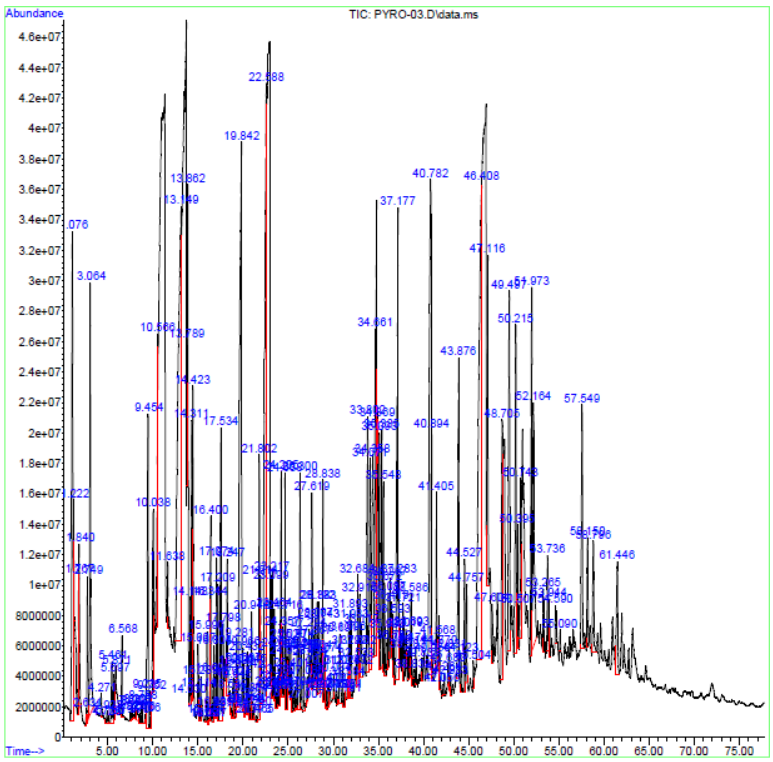

Figure 10: Graph of formulation no 1b

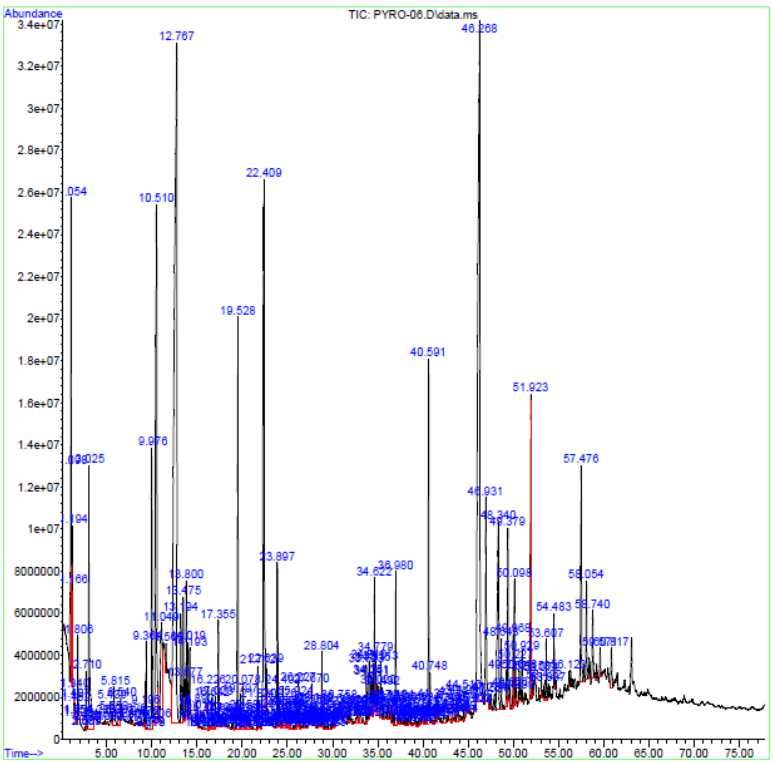

Figure 11: Graph of formulation no 2b

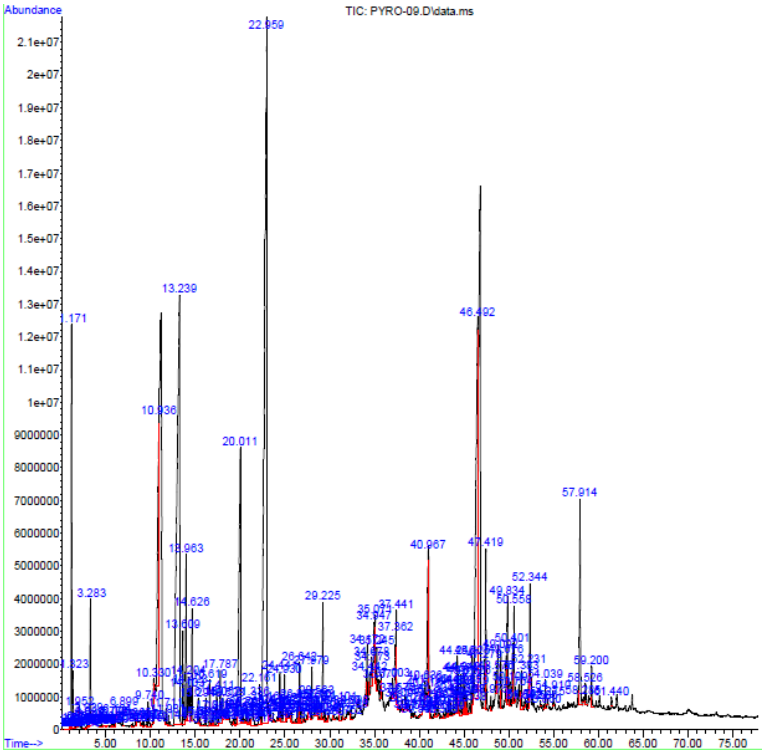

Figure 12: Graph of formulation no 3b

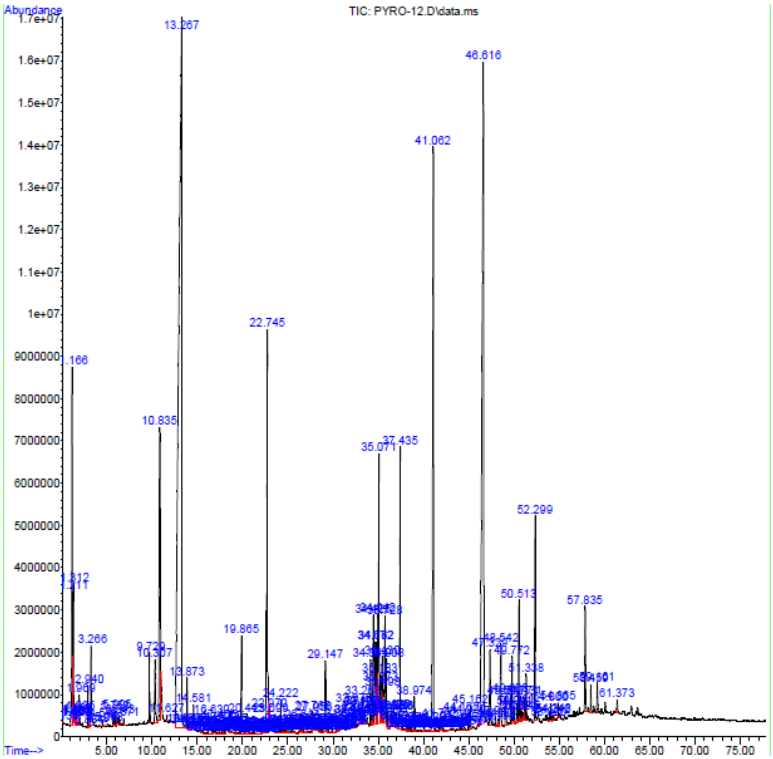

Figure 13: Graph of formulation no 4b

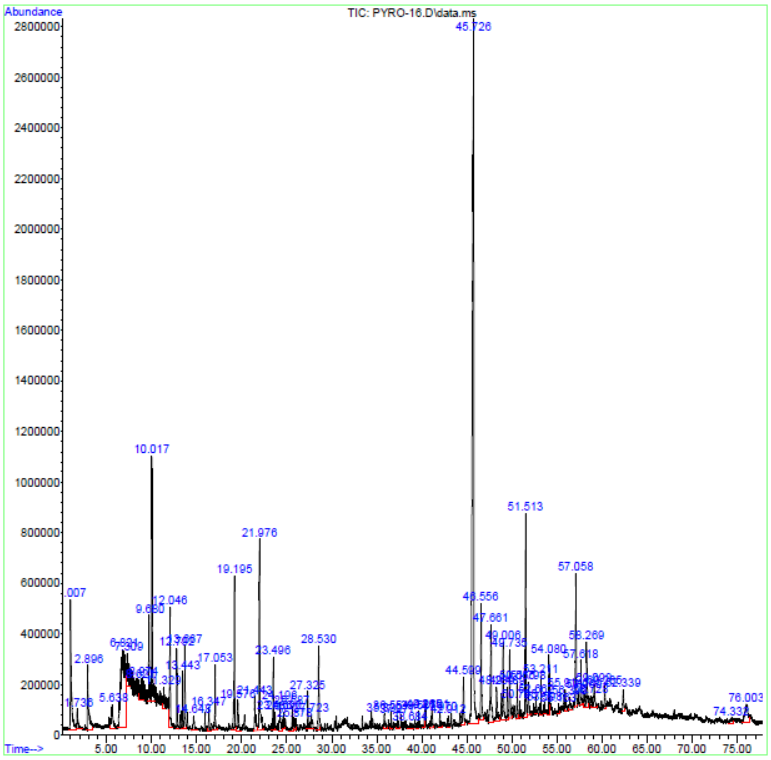

Figure 14: Graph of formulation no 5b

Formulation no	Retention time (min)	ID	Quality
1b	13.149	Benzyl Alcohol	98
2b	12.767	Benzyl Alcohol	98
3b	22.959	p-Isopropenylphenol	93
4b	13.267	Benzyl Alcohol	98
5b	45.726	Benzalphthalide	47

Table 8: Gaseous products of formulation 1b, 2b, 3b, 4b, 5b

Figure 10 until figure 14 show the graph of no. of existing peaks for gaseous produced versus the retention time for formulation no 1b, 2b, 3b, 4b and 5b. The dominant gaseous products for every formulation are shown in Table 8.

ALUMINA TRIHYDRATE (ATH)

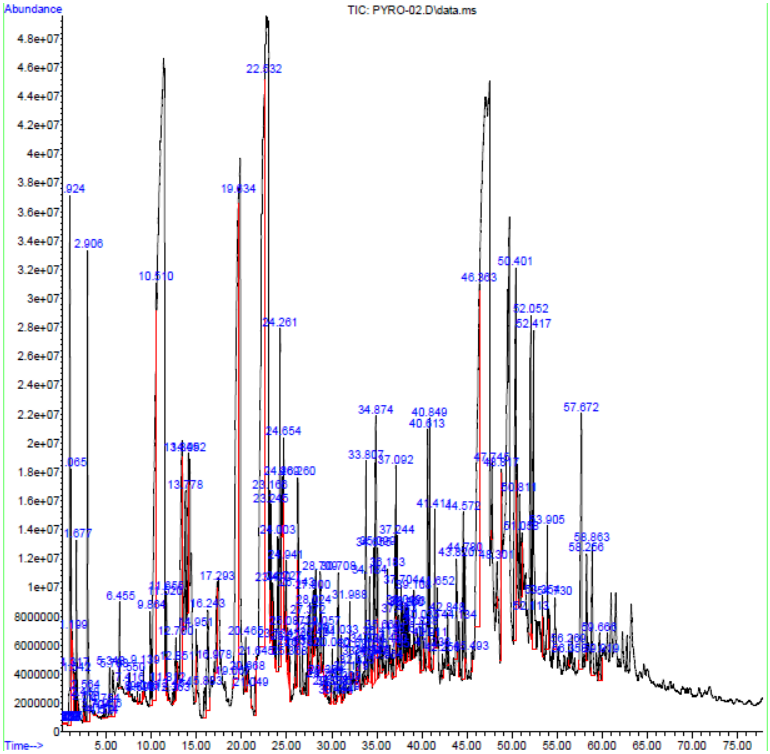

Figure 15: Graph of formulation no 1c

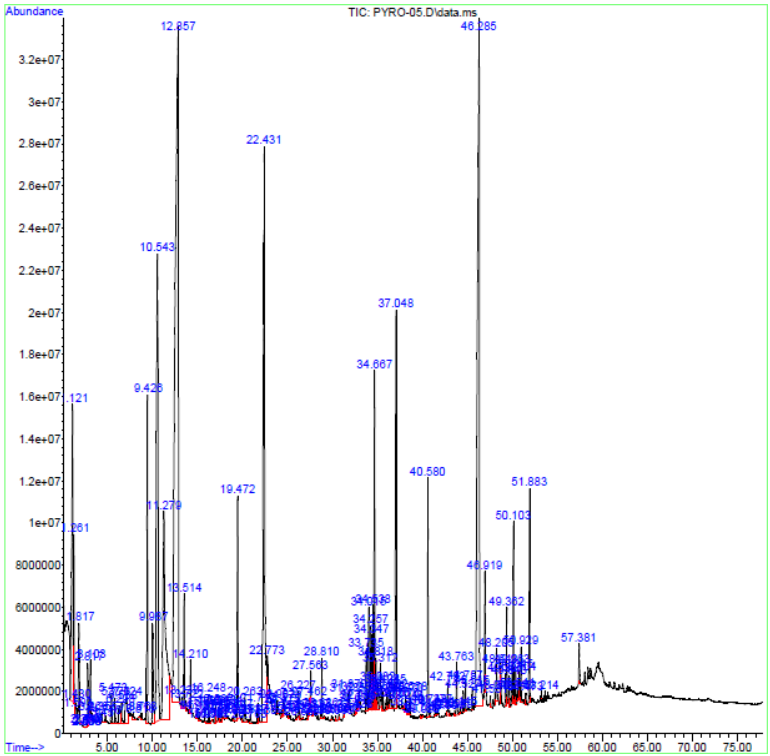

Figure 16: Graph of formulation no 2c

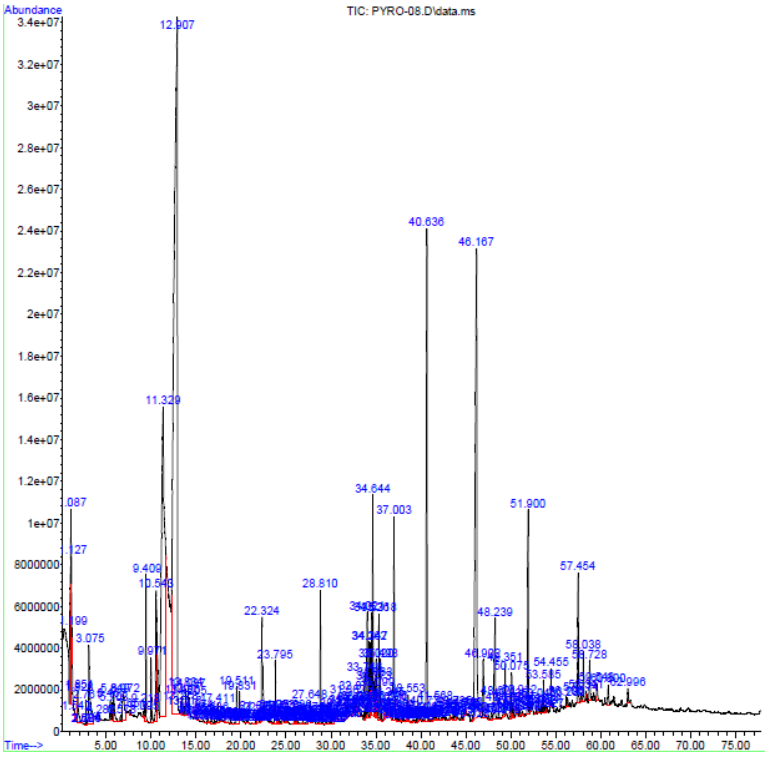

Figure 17: Graph of formulation no 3c

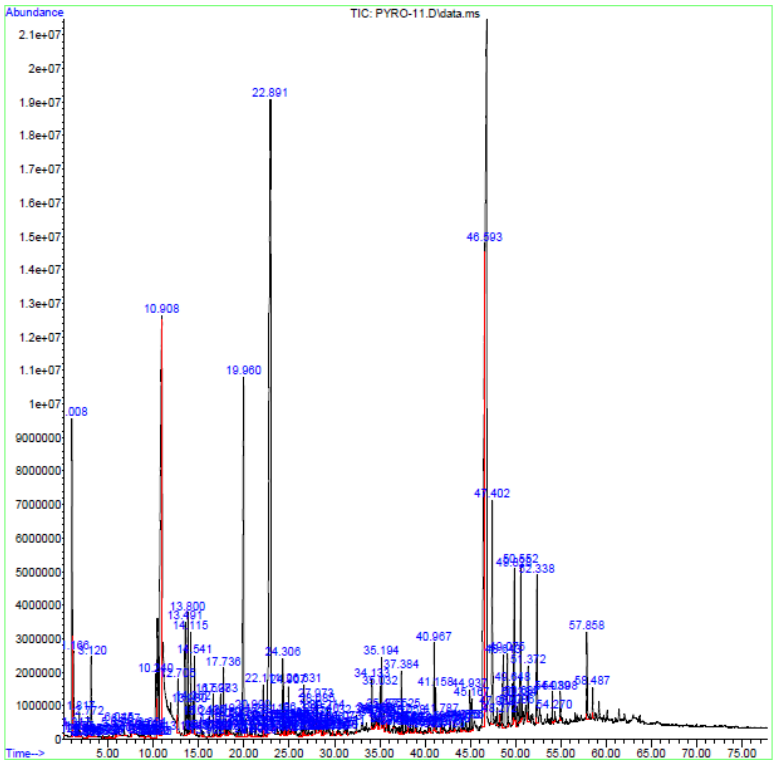

Figure 18: Graph of formulation no 4c

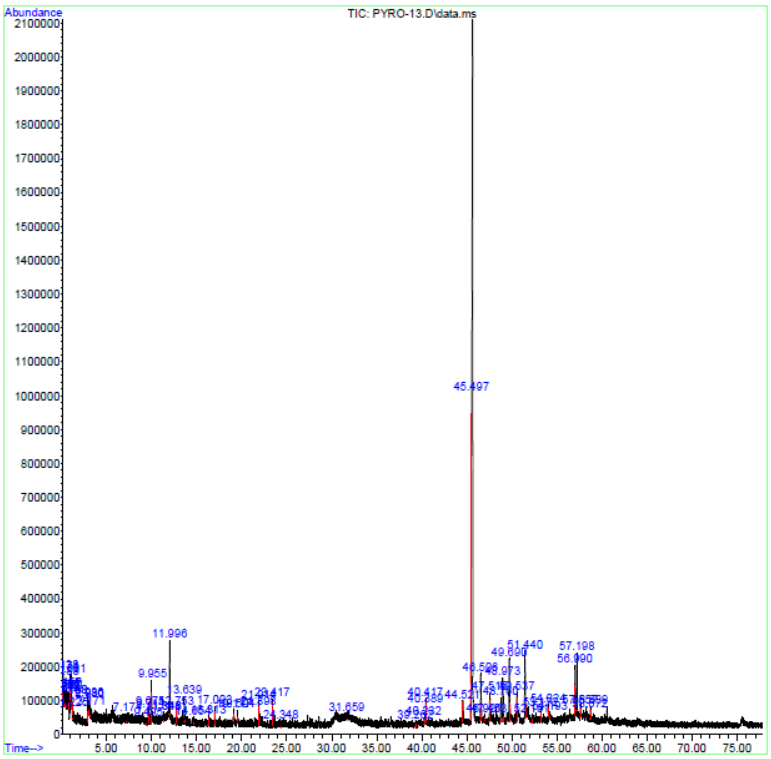

Figure 19: Graph of formulation no 5c

Formulation no	Retention time (min)	ID	Quality
1c	22.532	p-Isopropenylphenol	90
2c	12.857	Benzyl Alcohol	98
3c	12.907	Benzyl Alcohol	98
4c	22.959	p-Isopropenylphenol	93
5c	45.497	Benzalphthalide	38

Table 9: Gaseous products of formulation 1c, 2c, 3c, 4c, 5c

Figure 15 until Figure 19 show the graph of no. of existing peaks for gaseous produced versus the retention time for formulation no 1c, 2c, 3c, 4c and 5c. The dominant gaseous products for every formulation are shown in Table 9.

TALC

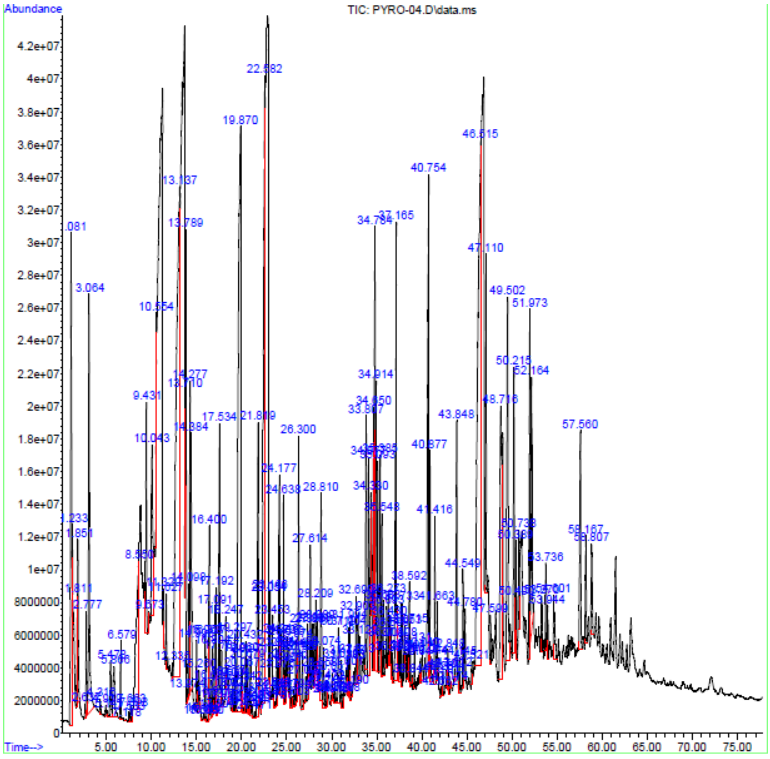

Figure 20: Graph of formulation no 1d

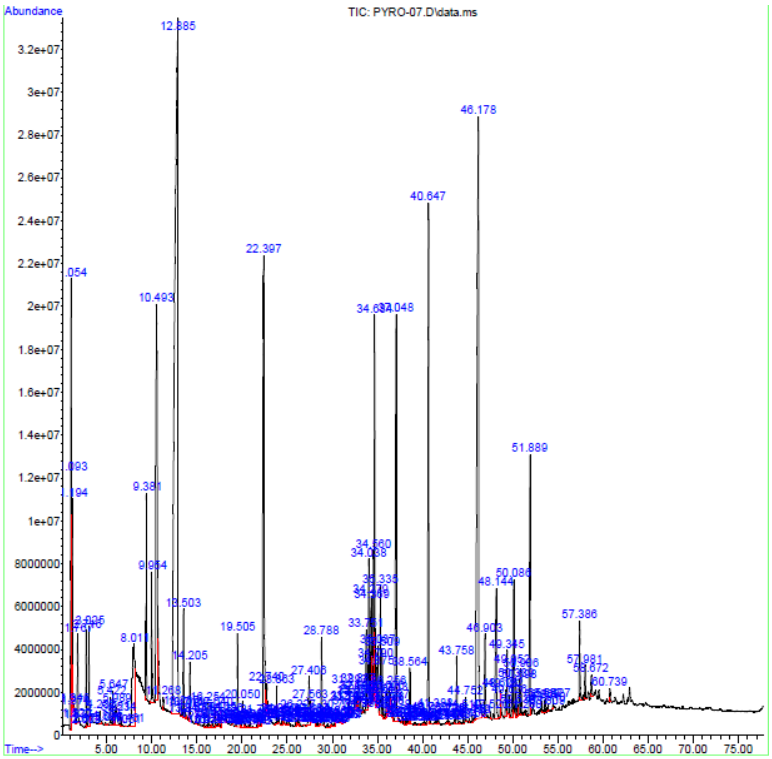

Figure 21: Graph of formulation no 2d

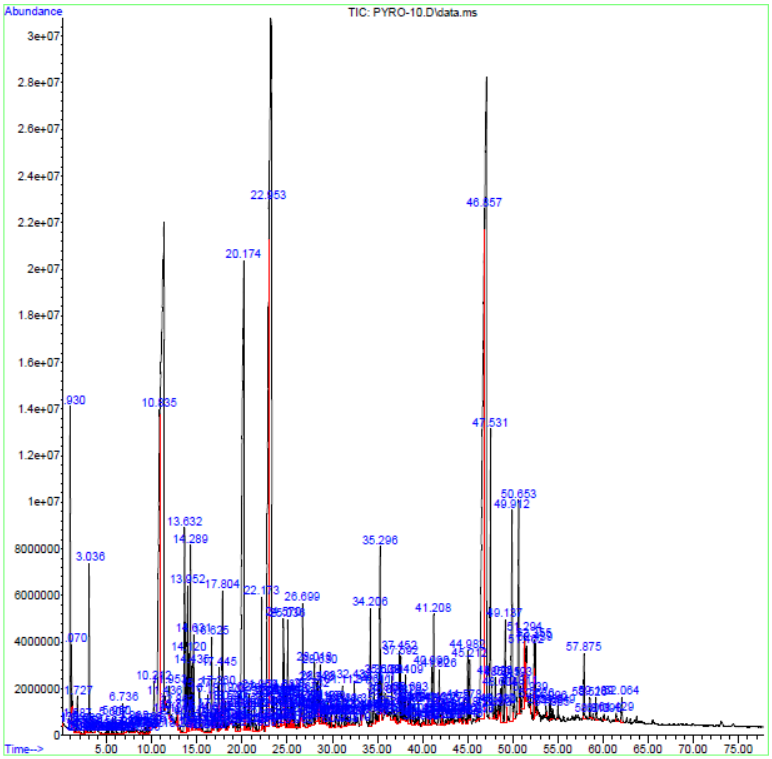

Figure 22: Graph of formulation no 3d

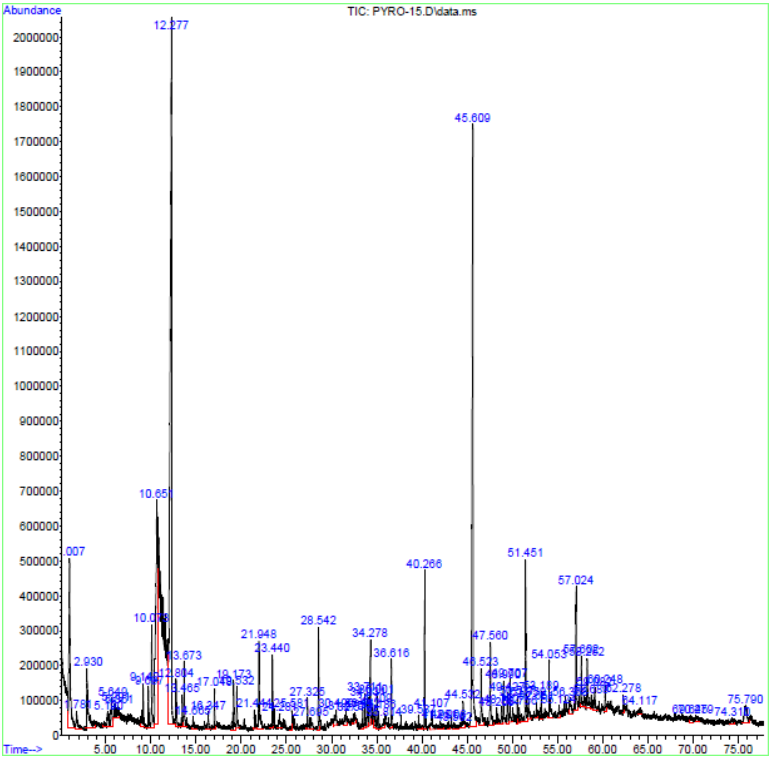

Figure 23: Graph of formulation no 4d

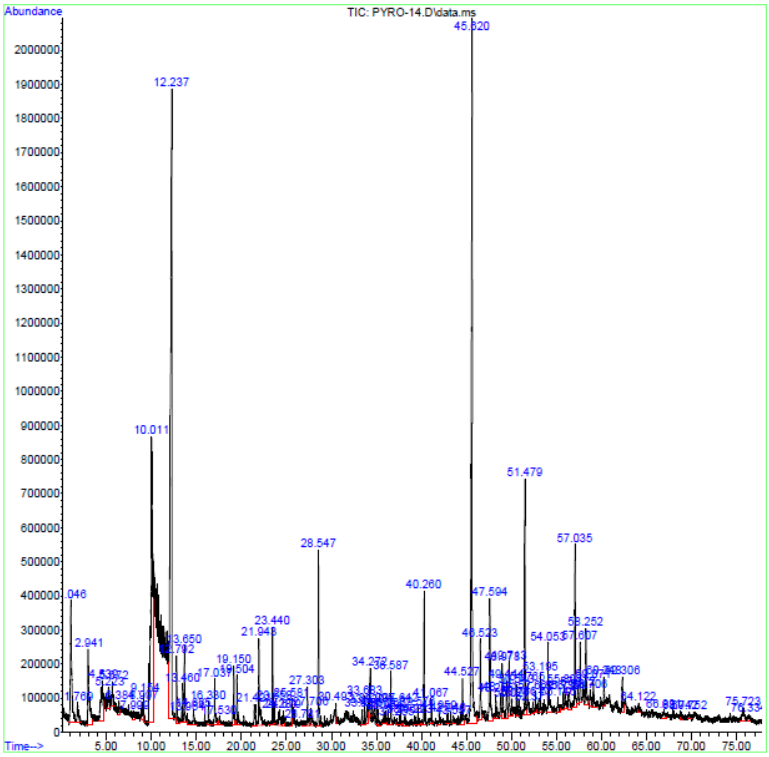

Figure 24: Graph of formulation no 5d

Formulation no	Retention time (min)	ID	Quality
1d	13.137	Benzyl Alcohol	98
2d	12.885	Benzyl Alcohol	98
3d	46.857	Phenol, 4,4'-(1-methylethylidene)b is-	95
4d	12.277	Cyclooctyl ethylphosphonofluoridoate	23
5d	12.237	Cyclooctyl ethylphosphonofluoridoate	17

Table 10: Gaseous products of formulation 1d, 2d, 3d, 4d, 5d

Figure 20 until Figure 24 show the graph of no. of existing peaks for gaseous produced versus the retention time for formulation no 1d, 2d, 3d, 4d and 5d. The dominant gaseous products for every formulation are shown in Table 10.

4.2 X-Ray diffraction test result

Without Filler

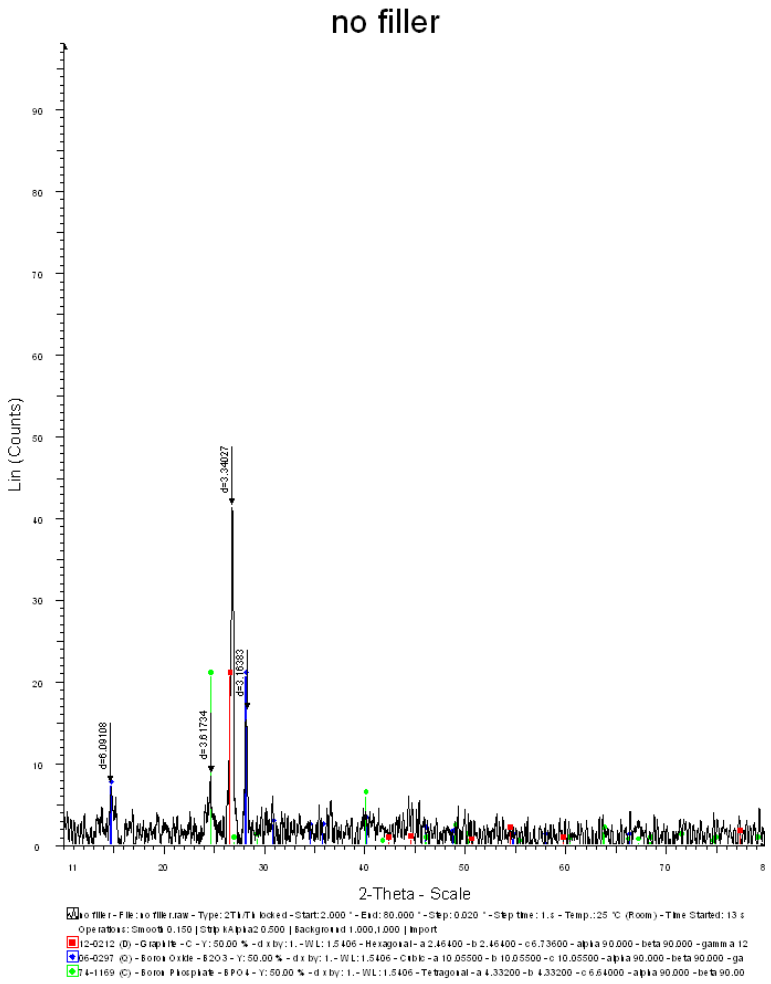

Figure 25: Graph of without Filler Compound

Alumina Filler

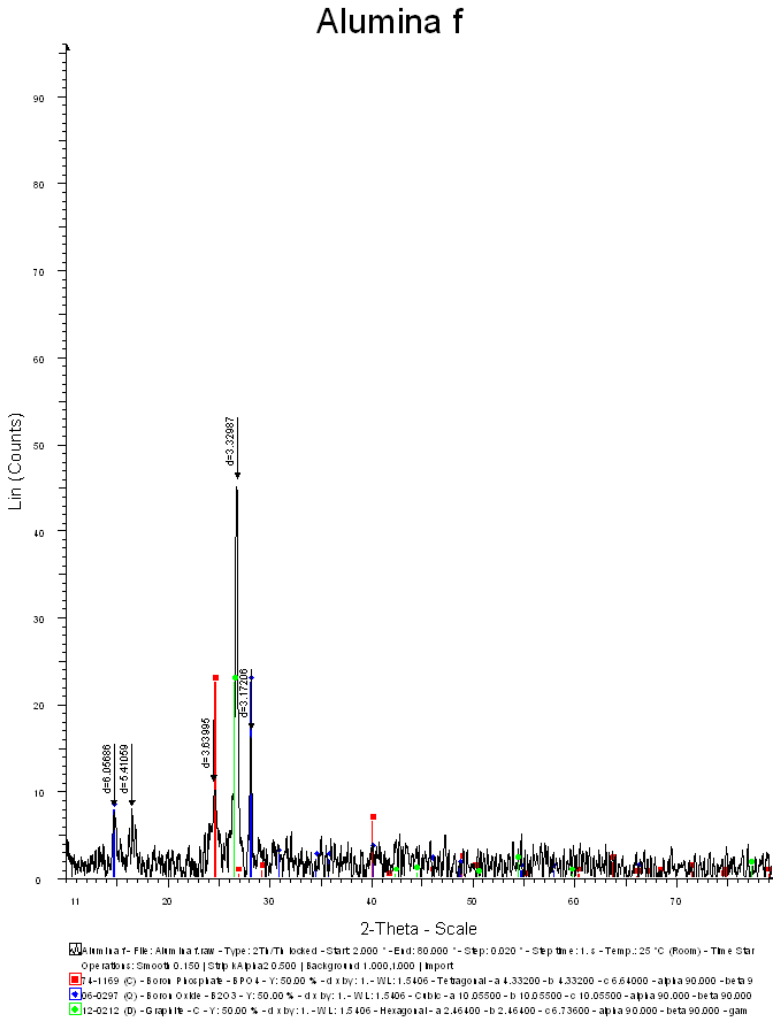

Figure 26: Graph of Alumina filler compound

ATH Filler

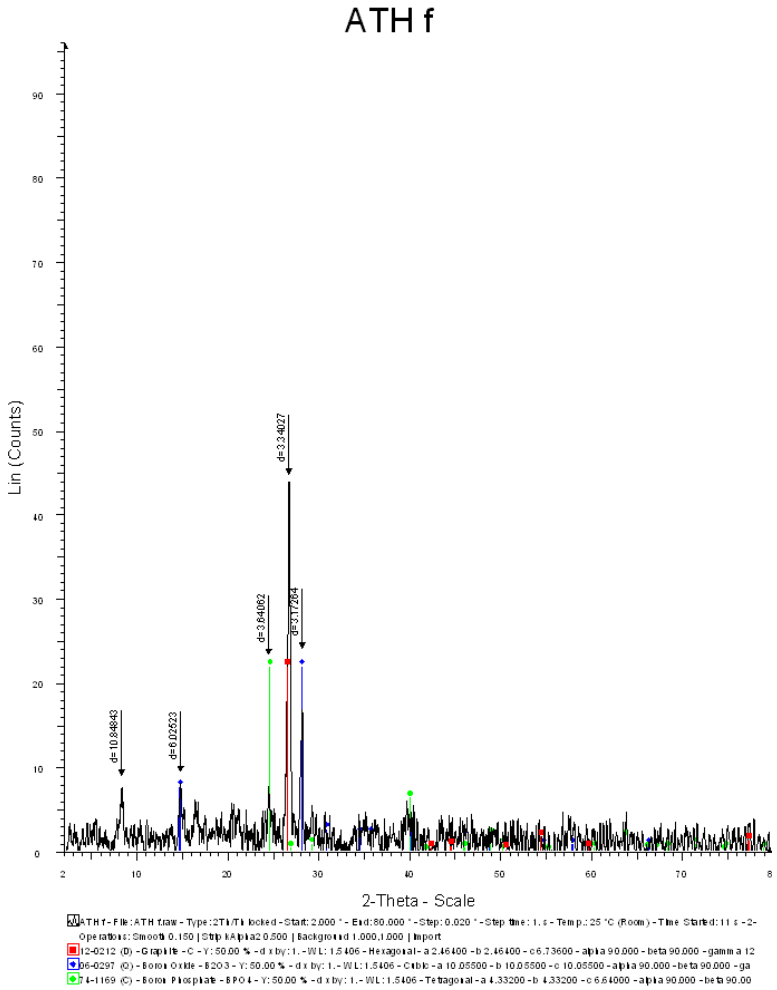

Figure 27: Graph of ATH filler compound

Talc Filler

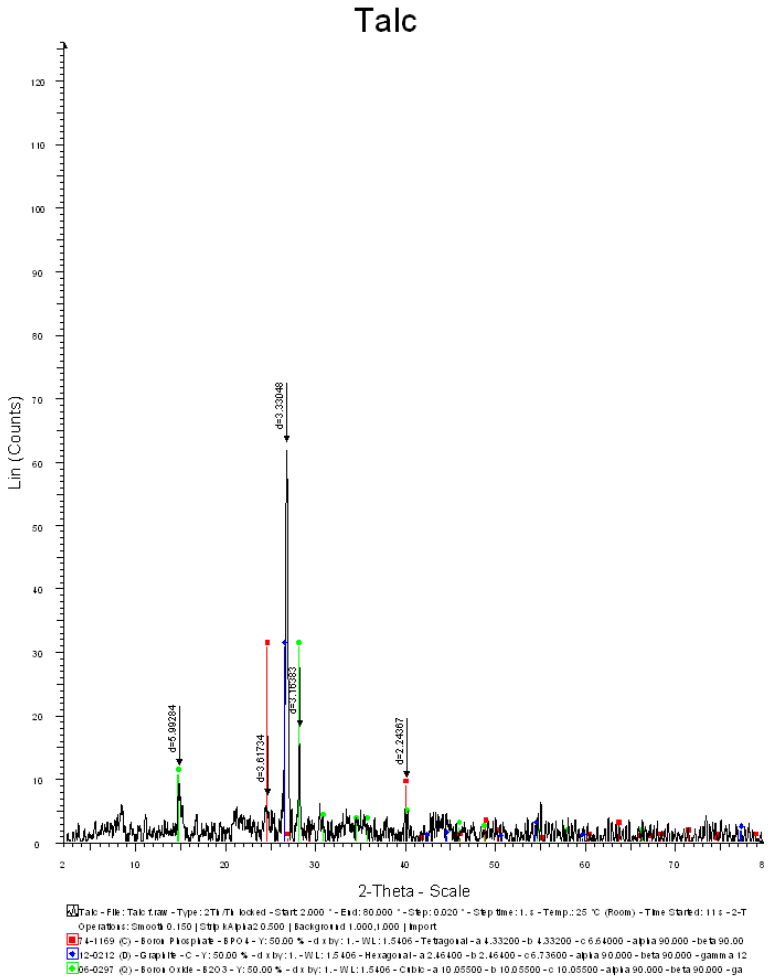

Figure 28: Graph of Talc filler compound

Figure 25 until Figure 28 show the presence of graphite, boron phosphate and boron oxide for all the fillers similar with the formulation without filler [8]. These compounds are stable at high temperature and effective for reducing heat penetration to the surface of the structural.

4.3 Discussions

Based on the results from GCMS test, the higher correlation area in the above graph is picked as the dominant gas. For the coating with no filler which is formulation no 1a, the higher correlation area happens at retention time of 46.071 minutes. During this period, the machine integrates the graph and gives 3 choices of the possibility gaseous. The gas with higher quality has been picked as the exact one which is Phenol, 4, 4'-(1-methylethylidene) bis- that have quality of 98. This gas with formula $C_{27}H_{32}O_2$ has molecular weight of 388.54, boiling point of 400.8^{o}C at 1atm and flash point of 192.4^{o}C. According to the Ministry of Environment and Health of Canada, this compound is acutely toxic to aquatic organisms and can also impact the normal development of individual offspring [13]. So it is not practicable to use the formulation without the mineral filler.

For the alumina, benzyl alcohol become the most dominant gas as it has been produced at formulation no 1b, 2b and 4b. This compound has formula $C_6H_5CH_2OH$ with molar mass 108.14 g mol^{-1} and boiling point at 205^{o}C. Another gas produced is p-Isopropenylphenol at formulation no 3b. This gas has molecular formula of $C_9H_{10}O$. According to the Material Safety Data Sheet for p-Isopropenylphenol by Chembase, the inhalation of this gas in bulk can cause the individual having headache, dizziness, nausea, shortness of breath, coughing and insomnia [14]. However, this health effects can be overcame by taking the victims to fresh air immediately. Besides that, there is another carbon compound of gas produced which is benzalphthalide at formulation no 5b. This gas has molecular formula of $C_{15}H_{10}O_2$ and molecular weight of 222.24. According to the Material Safety Data Sheet Benzalphthalide by Agros Organics Company, this kind of gaseous compound may cause respiratory tract irritation to victims [15]. As a solution, remove the victims from the exposure to the fresh air immediately.

For the Alumina Trihydrate (ATH), benzyl alcohol produced as dominant gas at formulation no 2c and 3c. Meanwhile, p-Isopropenylphenol produced at formulation no 1c and 4c. For formulation no 5c, the Benzalphthalide has been detected as dominant gas.

For talc filler, benzyl alcohol has been dominant gas at formulation no 1d and 2d. Phenol, 4, 4'-(1-methylethylidene) b is- is produced at formulation no 3d. For

formulation no 4d and 5d, Cyclooctyl ethylphosphonofluoridoate has been identified as the dominant gas. This compound has molecular formula of $C_{10}H_{20}FO_2P$. This gas which is classified in organic compound has not been studied detail yet by people.

Through the observation, these gaseous products from the minerals based are carbon compound or known as organic compound. All of them contain carbon element in their respective molecular weight. Organic compound has been used frequent in human daily life application from the medicine until the vehicles that use organic compound. These gaseous products cannot bring much harm to the human being specifically to the victim of the fire occasion unless they inhale the gaseous in bulky compare to the halogenated based.

For instance, most of the frequent gas that produced for all the samples is benzyl alcohol. It is a colorless liquid with mild pleasant aromatic odor. It can be useful for solvent due to its polarity, low toxicity and low vapor pressure. It is partially soluble in water and completely mixable in alcohols and diethyl ether. It can be used as a general solvent in the formulation of ink and lacquers, soap, perfume and flavor industries and as an intermediate in the synthesis of polypeptiedes. It also can be used as a non reactive compound where it reduces the viscosity and raises the flexibility of epoxy resin coatings.

In term of safety, according to the Registry of Toxic Effects of Chemical Substances of the U.S National Institute of Occupational Science and Health, benzyl alcohol is a non toxic material unlike the halogens gaseous. It also is a non corrosive and stable liquid. In the presence of air, it will very slowly oxidize to benzaldehyde. If the trapped victims of fire occasion inhale the gas, they can be recovered by just only bring and expose to the fresh air as soon as possible. According to the Hazardous Material Identification System of the National Paint and Coating Assn (HMIS), benzyl alcohol can be classified as below

Category	Hazardous (out of 10)
Health	2
Flammability	1
Reactivity	0

Table 11: Level of Hazardous of Benzyl Alcohol

The study also shows that there are less peaks exist in higher percentage of the mineral filler. So the higher percentage of mineral fillers give off less gaseous products compare to the no filler and lower percentage of mineral fillers used. Pyrolysis analysis confirms that the higher composition of mineral filler is an environmental friendly formulation as it releases less gaseous products in terms of type and concentration of gaseous product

For the higher percentage mineral fillers which are the best for giving off less gaseous products, there is a comparison to do in order to know the best mineral filler to be used among these three. The comparison which in term of its amount of gaseous products produced during the decomposition is shown in table 12.

Type	Alumina 5%	ATH 5%	Talc 5%
No of Peak with Retention Time	1. 10.017 min 2. 21.97 min 3. 45.726 min 4. 51.513 min	1. 45.497 min	1. 12.277 min 2. 10.651 min 3. 45.609 min

Table 12: Comparison between the higher percentage mineral fillers

Based on table 12, study can show that the ATH 5% is the better among these mineral fillers to be used. This is because the filler only has lower amount of its gaseous products which can be identified at retention time of 45.497 minutes. This can be said that this filler is more environmental friendly compare to the others.

CHAPTER 5: CONCLUSION

5.1 Conclusion

This project was carried out with the main objective to develop mineral based intumescent fire retardant coating by study the characteristics of its gaseous products. It can be concluded from the results obtained that the highest percentage of mineral fillers give off less amount of gaseous products which are mostly organic compounds and the preferable filler to be used among these fillers is ATH 5%. This study also shows that the residual char of all the samples with mineral fillers still consists of graphite, boron oxide and boron phosphate which are stable at higher temperature to protect the substrate from being destroyed by fire.

5.2 Recommendations

It is recommended to carry out further study with similar objective for:

1. Other intumescent fire retardant with other reinforcements such as formulation with fiber glass as the reinforcement.
2. The mineral based intumescent fire retardant coating that has been undergone the water immersion test and weather ability test to compare the characteristics of its gaseous products.

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