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Effects of Emission Characteristics on Elemental Composition of Selected PVC Ceiling Materials

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ABSTRACT

This research work determined the emission characteristics and elemental composition of selected PVC ceiling materials common in Nigerian markets especially during service. This research work determined the emission characteristics and elemental composition of selected PVC ceiling materials common in Nigerian markets. The emission data and elemental structure gave insight to appraise their suitability as ceiling materials. Three PVC ceiling materials were used for this analysis: Nigerian made PVC, layered Composite PVC and white PVC. Rutherford Backscattering Spectrometry (RBS) was performed to obtain the elemental structure of the ceiling materials using Ion Beam Analysis facility. 0.05 kg of the samples were combusted in a controlled fire chamber and the gasses emitted; CO, SO_2, NO, and volatile organic compounds (VOC) were identified using four gas analyzers. Elements were detected in total and data collected from the experiment were analyzed. Results showed that Nigerian made PVC has the highest total noxious gas among the three samples with value of 3732.5 ppm while layered composite PVC has the lowest among the PVCs with the value of 1477.5 ppm. The elemental make-ups of the samples influence their emission characteristics. The study established that PVC samples were noxious in terms of their emission characteristics due to the effects of their elemental basis.

KEYWORDS: Emission Characteristics, Elemental Composition, Noxious Gas, Gas Analyzer.

1. INTRODUCTION

The gaseous product from combustible materials reveals their exothermic and turbulent interactions. This flame may be so intense to prevent humans from escaping. The noxious gases may easily lead to suffocation and death, this currently happens in Nigeria. This study will therefore provide relevant insight to the elemental characteristics of PVC ceiling materials and the gaseous substances emitted. Such information may be useful in predicting and reducing uncontainable fire outbreaks in Nigeria. It will also be relevant in giving advice with respect to the best way to handle unused remnants of ceiling PVC waste products. An understanding of the element that makes up the PVC samples will help to report the presence of harmful and combustible elements which will either cause health hazard or fire outbreak. Fire outbreak is preventable if and only if preventive measure is really adhered to by stakeholders and standard organizations.[1]

The specific objectives of this paper are to determine the elemental composition of PVC ceiling materials forecast their emission characteristics and report the integrity of the materials.

Fire motion studies the interaction among disciplines such as chemistry, metallurgy, fluid mechanics and heat transfer on how fire initiates, propagates and decomposes.[2] This also reveals the aerodynamics of the fire. The flame structure and velocity are very significant and may account for its prowess within the period of the existence of the fire. Fire can be described as follows: "A rapid oxidation process, which is a chemical reaction resulting in the evolution of light and heat in varying intensities."[3] The vigorous exothermic energy release of a material in the exothermic process of combustion releasing heat, visible illumination and various reaction products. It can also be explained in terms of the Fire Tetrahedron a geometric representation of what is required for fire to exist, namely: fuel, an oxidizing agent, heat, and an uninhibited chemical

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Table I. Temperature behaviours.

°C	°F	Response
37	98.6	Normal human oral/body temperature
44	111	Human skin begins to feel pain
48	118	Human skin receives a first degree burn injury
55	131	Human skin receives a second degree burn injury
62	140	A phase where burned human tissue becomes numb
72	162	Human skin is instantly destroyed
100	212	Water boils and produces steam
140	284	Glass transition temperature of polycarbonate
230	446	Melting temperature of polycarbonate
250	482	Charring of natural cotton begins
>300	>572	Charring of modern protective clothing fabrics begins
>600	>1112	Temperatures inside a post-flashover room fire

Source: (National Institute for Standards and Technology Gaithersburg,[22]).

reaction.[4,5] Table I shows the fire temperature behaviour on matter.

There are various measures of fire such as the ignition time, mass loss, smoke generation heat release rates amongst others.[6,7] The thickness of a material have an effect on the fire spread and ways to inhibit the spread of fire were suggested such as employing nanotechnology as a thermal barrier, epoxy, resin and vinyl ester.[8–15] Various authors recommended the use of innovated ceiling materials due to their excellent thermal properties, however did not account for the emission of these materials.[16–21]

The toxicity of some gaseous products of combustion is well known, but the concentration of these gases in an actual fire is not well known, even from simulated conditions in laboratory experiments. When gaseous products are formed is it can be determined by the chemical composition of the material, the amount of available oxygen, the temperature, and the rate of temperature change. Experimental fires in typical structures have shown that in many cases the minimum concentration of oxygen for survival, or the maximum breathing level temperature for survival, was reached before any toxic gases attained a lethal concentration.[22] The hazard of toxic fire gases is often psychological and sometimes overemphasized, fire fatalities from the inhalation of hot air and gases are significant proportion of fire deaths. Children are spotted as the vulnerable victims of fire accidents.[23] Plastic materials are based on carbon-containing polymers; the gaseous products of combustion include carbon dioxide and carbon monoxide. Carbon dioxide is not generally considered toxic, but it can present hazard in two ways. First, it represents oxygen depletion. In the complete absence of ventilation, a certain volume of carbon dioxide represents removal of an equal volume of oxygen. Secondly, it over stimulates the respiratory system, causing an abnormally high intake of other gases, resulting in toxic or lethal effects which would not otherwise have been attained. A carbon dioxide concentration of 1.8 percent is said to increase speed and depth of breathing 50 percent, and a 2.5 percent concentration is said to increase breathing rate by 100 percent.[24]

Carbon monoxide ranks first as a cause of fire deaths because it is always formed by an uncontrollable accidental fire, in which oxygen concentrations and availability are novel ideals for complete oxidation to carbon dioxide. The maximum concentration of carbon monoxide for survival is considered to be 1.28 percent, at this higher level, a person will become unconscious after two or three breaths and probably die in one to three minutes.

Carbon monoxide combines with the haemoglobin in the blood to form carboxy-hemoglobin, displacing oxygen in the blood, leading to anoxia and death. The gaseous products of combustion from polymers containing carbon, hydrogen, and oxygen may include, in addition to carbon dioxide, carbon monoxide, and water, other gases which contain carbon, hydrogen, and oxygen. Gases which contain carbon and hydrogen may include butane and other aliphatic hydrocarbons, and benzene and other aromatic hydrocarbons. Gases which contain carbon, hydrogen, and oxygen may include acetone and other ketones, formaldehyde and other aldehydes, acetic acid and other acids, and ethyl acetate and other esters. Many polymers contain other elements in addition to carbon, hydrogen, and oxygen, and their gaseous products of combustion may include other gases in addition to gases containing only carbon, hydrogen, and oxygen. The gaseous products of combustion from polymers containing sulfur may include sulfur dioxide and hydrogen sulfide.[25]

The gaseous products of combustion from polymers containing nitrogen may include ammonia, hydrogen cyanide, and nitrogen dioxide. The gaseous products of combustion from polymers containing chlorine may include hydrogen chloride. Some gases such as sulfur dioxide and ammonia are extremely irritating at concentrations well below lethal levels, and a person will normally leave the burning system or put on protective breathing apparatus, if he is able, before suffering serious effects. Hydrogen sulfide is identified by its "rotten egg" odour, but continued exposure to concentrations above 0.2 percent may paralyze the sense of smell. Hydrogen cyanide has a characteristic bitter almond odour which may be masked by other odour. Nitrogen dioxide is identified by its reddish-brown colour, but it tends to anesthetize the throat and its toxic effect is often delayed. Fatalities may occur hours or days after exposure although the exposed persons may show no immediate ill effects.[26]

The principal hazard of smoke is that it hinders the escape of occupants and the entry of fire-fighters seeking to locate and extinguish the fire. It can contribute to panic conditions because of its blinding and irritating effects. In many cases, smoke reaches untenable levels in exit ways before temperature reaches untenable levels.

The size and distribution of smoke particles affect the optical absorption level at which sight obscuration is essentially total, as does the degree of irritation to the observer. Smoke density is influenced by the rate of burning and degree of ventilation, and is generally in inverse proportion to the degree of ventilation.[26]

The failure of structural components through heat damage or burning can present a serious hazard, perhaps the most dramatic examples are the collapse of weakened floors under the weight of fire-fighters and the collapse of walls and roofs on persons beneath them.

Various mechanical tests such as the tensile and impact tests offer useful information as per the strength characteristics, responses, and behaviours of engineering materials when subjected to loads over short periods of time.[27]

2. MATERIALS AND METHODS

Three (3) commonly used PVC samples were obtained from the Nigerian market. The samples are shown in Figure 3. The emission characteristics of the samples were analysed in a controlled locally designed combustion chamber which was purged of particle to achieve red hot flame. The combustion analyzers were placed near the flame and gasses concentrations were recorded such as VOC (Volatile Organic Compound), SO_2, CO, NO. The combustion analyzer revealed the gasses emitted and its emission characteristics so as to predict the amount of gaseous concentration that could be harmful to victims trapped in a fire incidence.

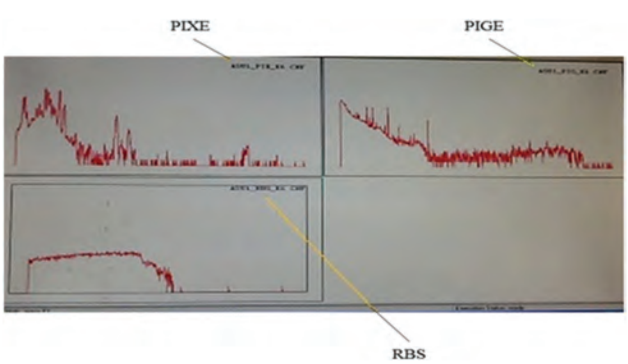

Fig. 1. Particle accelerator at centre for energy research and development, OAU.

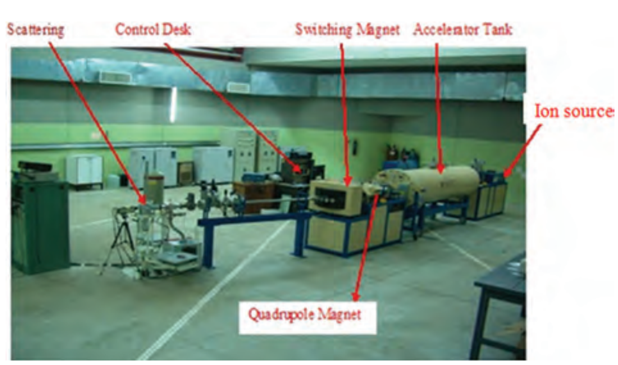

Fig. 2. A photo showing PIXE, PIGE and RBS spectra of a sample ASUI, acquired simultaneously with CERD system.

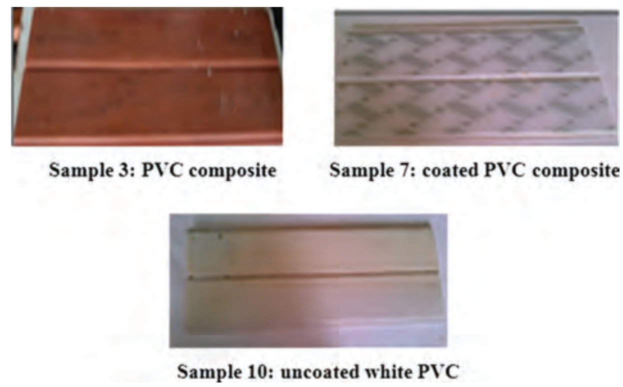

Fig. 3. PVC sample panels.

The elemental Structure of the PVC was carried out at the Centre for Energy Research and Development (CERD). The Rutherford Backscattering Spectrometry (RBS) experiment was performed using a 2.2 MeV alpha beam obtained from CERD ion beam analysis (IBA) facility. The facility is centered on a NEC 5SDH 1.7 MV Pelletron Tandem Accelerator, equipped with a radio frequency charge exchange ion source, Alphatross. The ion source is equipped to provide proton and helium ions. The end-station consists of an Aluminium chamber of about 150 cm diameter and 180 cm height. It has four ports and a window. Port 1 at 165° is for the RBS detector, port 2 at 135° is for Proton Induced X-ray Emission (PIXE) detector, and port 3 at 30° is for the Elastic Recoil Detector Analysis (ERDA) detector, the window at 0° is for observing the beam position and the size, while port 4 at 270° is for Proton Induced Gamma Emission (PIGE). The chamber has a sample ladder that can carry eleven 13 mm or 25 mm diameter samples. The end-station has a turbo pump and a variable beam collimator to regulate beam size, and an isolation valve.

The measurements were carried out with a beam spot of 8 mm in diameter and a low beam current of 10–15 nA and for a constant charge of 1.0 μC on target. The RBS detector is a Canberra PIPs detector with 50 mm^2 active areas, 300 μm thick silicon crystal and an energy resolution of $\sim$12 keV. Canberra Genie 2000 (3.1) software was used for the simultaneous acquisition of the PIXE, RBS and PIGE data. SIMNRA computer code was used for RBS data analysis.

3. RESULTS AND DISCUSSION

3.1. Elemental Structure of Selected PVCs Samples

From the analysis carried out employing Rutherford Backscattering Spectrometry (RBS) as shown in plates 1 and 2, the elements detected are as follows: oxygen, carbon, nitrogen, silicon, chlorine, sodium, calcium, potassium, aluminium, titanium, lead, iron, sulphur and magnesium. The presence of oxygen detected in all samples reveals that they will combust in different degrees.

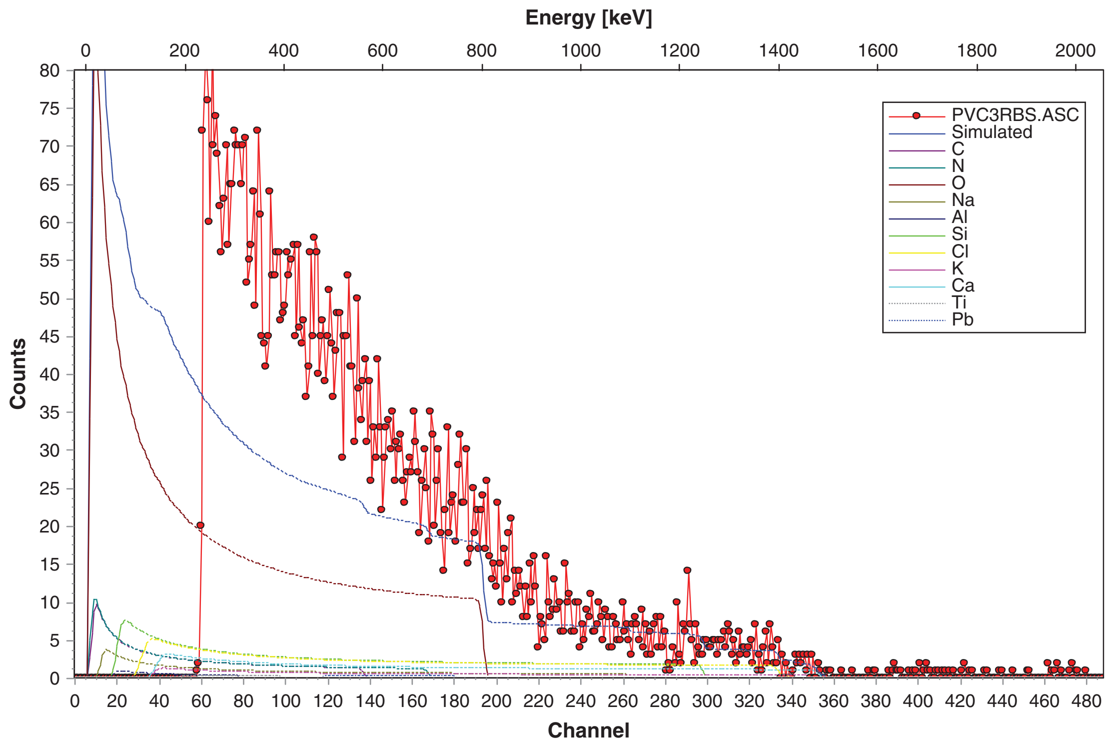

Fig. 4. Layer 1: Thickness 20000 (E 15 atoms/cm^2) of the elemental structure of PVC3-RBS.

Sample 3 with 63.6% will burn faster than samples 7 and 10 which maintained same 18% presence of oxygen. Sample 7 and 10 are expected to have more CO due to the high carbon content of 77.9% while sample 3 will have less smoke emission due to low carbon content of 15.9%. Sample 3 has highest nitrogen content of 10.6% compared to samples 7 and 10 with same 3% content. Sample 3 has 3.5% constituent of silicon while samples 7 and 10

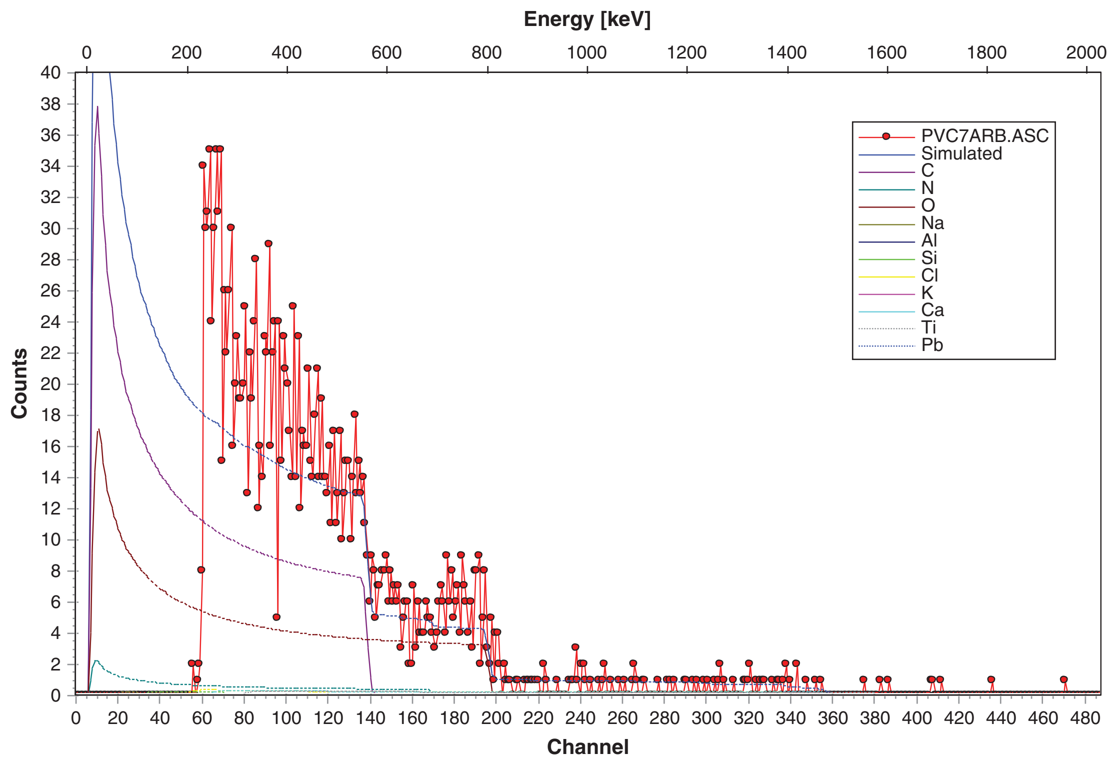

Fig. 5. Layer 1: Thickness 20000 (E 15 atoms/cm^2) of the elemental structure of PVC7-RBS.

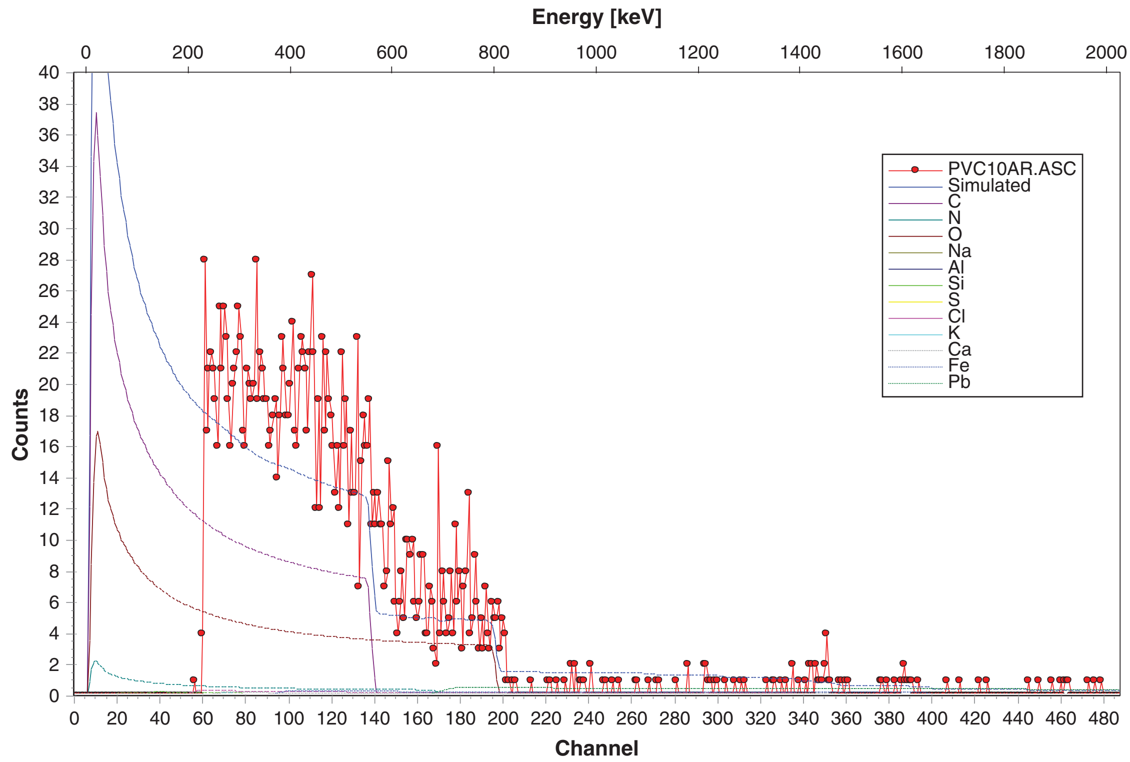

Fig. 6. Layer 1: Thickness 20000 (E 15 atoms/cm^2) of the elemental structure of PVC10-RBS.

Table II. Peak concentration of selected samples at 0.05 kg.

Sample	Peak concentration (ppm)					Total noxious gasses
	VOC	CO	SO_2	NO	H_2S	
3	1999	1722.0	2.5	9.0	ND	3732.5
7	740.6	732.0	1.1	3.8	ND	1477.5
10	842.8	726	0.0	0.2	20.9	1589.9

have 0.2% which are insignificant. The presence of chlorine in sample 3 is 2.2% while both samples 7 and 10 with 0.23%. The combination of this element with sulphur and hydrogen will account for char during combustion analysis. The elemental structures of the PVC samples are shown in Figures 4–6 and Table II. Samples 3 and 10 contain lead, a heavy metal, which is harmful to human being and should be discouraged as a minimum amount of it in any sample is harmful. It can affect the reproductive organ of an adult and reduce the intelligent quotient of children exposed to it by 60% compared to those not exposed to it.

The alkaline metals such as sodium and potassium are non-toxic in their free states while magnesium and aluminium are as well, non-toxic in their free states. Sample 3 gives the most potential effect for aluminium oxide. The acidity result because of the combination of sulphur, hydrogen and oxygen makes the samples particle unsafe in the cause of fire outbreak.

3.2. Concentration of Gas Emission and Temperature of Select Samples

Table II shows that Sample 3 had the highest volatile organic compound (VOC) the value of which is 1999 parts per million (ppm) hence most hazardous while sample 7 has the lowest with 740.6 ppm. CO value rose before flame and reduced significantly after the flame extinguished.

Table III. Elemental composition of samples, all @ layer 1: Thickness 20000 (E 15 atoms/cm^2).

Sample type	Elemental composition (%)												
	O	C	N	Si	Cl	Na	Ca	K	Al	Ti	Pb	Fe	S	Mg
PVC3-RBS	63.6	15.9	10.6	3.5	2.2	2.0	1.0	0.5	0.5	0.1	0.01	ND	ND	ND
PVC7-RBS	18.0	77.9	3.0	0.2	0.23	0.2	0.2	0.1	0.05	0.1	ND	ND	ND	ND
PVC10-RBS	18.0	77.9	3.0	0.2	0.23	0.2	0.1	0.1	0.05	ND	0.02	0.1	ND	ND

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Sample 3 has highest CO level with 1722.0 ppm unlike sample 10 with the value of 726 ppm which is due to their percentage elemental composition. Polyvinyl chloride samples ignited briefly due to the coating on it; but continued to smoulder all through the combustion process resulting in high value of CO. This is an indication of incomplete or inefficient combustion. Health and Safety Executive[26] specified the exposure time limit of 15 minutes for 200 ppm of CO. However, the CO level shown on Table I indicates that all the ceiling materials fell short of the survival level recommended. SO_2 is detected in samples 3 and 7 which will account for the presence of acid that causes irritation of the eye during fire outbreak. It is however not present in sample 10. The presence of hydrogen sulphide in sample 10 with value 20.9 ppm will give an irritating smell during outbreak of fire thus inducing suffocation. NO is highest in sample 3 with the value of 9 ppm and lowest in sample 10 with the value of 0.2 ppm. The presence of this compound during combustion can impede oxygen transport of the blood causing various health effects.

Sample 3 has the highest total noxious gas among all samples with value of 3732.5 ppm while sample 7 has the lowest among the PVCs with the value of 1477.5 ppm.

The differences in concentration of gaseous emission also are due to difference in the composition of the materials, the degree of exposure of the fire involved and analytical methods employed in the study.

4. CONCLUSION

The effects of emission characteristics on elemental composition of selected PVC ceiling materials are presented in this paper. The result shows that sample three has the total noxious gas and is due to its elemental structure which is comparably similar to samples 7 and 10 with lesser values. Oxygen combusts in varied degree in each sample and its percentage combination with carbon shows the smoke emission of each sample. This analysis shows that the samples are not excellent in their emission as revealed in their elemental structure and will emit noxious gasses in the case of fire outbreak.

Natural composites with low emission and eco-friendly should be explored as alternative to PVC composite ceiling materials.

It is important that manufacturers in Nigerian building industry have strong collaboration with Standard Organization of Nigeria in ensuring production of standard building ceilings that are less noxious in emission and composition so as to achieve an eco-friendly environment.

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