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Assessment Of The Levels Of Toxic Volatile Organic Compounds And Other Substances In The Air In A Plastic Recycling Environment Situated In Scientific Equipment Development Institute, Enugu.

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Abstract
Studies were carried out to assess the levels of toxic volatile organic compounds and other substances in the air in a plastic recycling environment situated in SEDI-Enugu using standard operational procedures and instrumentation.
The mean concentrations of the pollutants in the air were, 1.71 ± 0.13, 231.74 ± 3.42, 14.16 ± 2.06, 0.11 ± 0.06, 0.41 ± 0.12, 101.08 ± 4.66, 20.77 ± 3.29, 28.25 ± 1.73 and 4.11 ± 0.25$\mu g/m^3$ *for benzene, vinyl chloride, tetrachloroethylene, furan, formaldehyde, toluene, styrene,* $PM_{2.5}$ *and napthalene respectively.*
The mean levels of the VOCs and other substances in the air in the studied environment decreased in the following order: vinyl chloride > toluene > $PM_{2.5}$ *> styrene > tetrachloro ethylene > naphthalene > benzene > formaldehyde > furan.*
All the investigated air pollutants (VOCs and other substances) except vinyl chloride, formaldehyde and $PM_{2.5}$ *were within their respective recommended threshold limits in the air.*
Adequate provision and stricter use of protective materials by those working and inhabiting within the plastic recycling environment is recommended in order to safeguard them from undue exposure to this toxic volatile air pollutants especially at toxic levels.

Key words: *Plastic recycling, Plastic wastes, Volatile organic compounds, Environmental pollution , Health impact and Air pollutants.*

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I. Introduction

Plastics continue to benefit society in innumerable ways particularly in engineering, medicine and public health. Plastics are composed of a network of molecular monomers bound together to form macromolecules of infinite use in human society (North and Halden, 2014). Plastics are versatile, cost effective, require less energy to produce than alternative materials such as metal or glass and can be manufactured to have many different properties. Due to the characteristics, plastic polymers are used in multifaceted ways from packaging, decoration, storage, automative, medicinal to engineering materials. Plastics can be soft, transparent, flexible, cost effective, required little energy to produce, light weight and biocompatible (Andrady and Neal, 2009).

There are four major options for disposal of plastics and this includes land filling, incineration, recycling and biodegradation.

However, land filling, incineration and biodegradation requires space, a lot of energy is lost, has more negative environmental and health impacts and biodegradation of biodegradable plastics takes a long time and can contaminate the surrounding environment hence they are less fancied as a way of disposing plastic wastes (Hopewell *et al.*, 2009).

Plastic waste constitutes between 60 to 80% of aquatic and non-aquatic environmental debris and is one of the world's most pervasive pollution problems that is impacting negatively on the natural environment (Verma *et al.*, 2016). The durability of plastics and their potential for diverse applications including widespread use of disposable items were anticipated, but the problems associated with waste management and plastic debris were not (Kershaw *et al.*, 2011). Over the past 80years, plastic production and waste have dramatically increased part of a global waste crisis whose drivers have included rapid urbanization, increasing consumption in both high and low income countries and increased production of throw away products.

Indeed, from raw materials extraction through plastic production and use, plastic wastes represent the failure of a predominantly fossil fuel based linear economic system (Vivek, 2014).

Recycling represents the easiest, safest and the most economic means of reducing the ugly and hazardous impact of plastic wastes in the environments especially in developing countries of the world (Forrest *et al*., 1995).

However, in recycling plastics especially from the approach adopted by developing and third world countries, the plastic wastes collected for recycling are not usually well sorted out before crushing, pelletizing and use in production of new plastic products.

Hence, the worry from the environmental pollution and toxic a gaseous releases stems from the use of these plastic wastes with different chemical compositions production and applications. According to Hopewell *et al*., (2009), the nature and level of the pollutant gases produced from melting these plastics wastes is dependent on their different chemical compositions and applications.

Equally, the use of plastic additives and colourants in the manufacture of the various plastic wastes contributes in the release of various gaseous pollutants called volatile organic components into the atmosphere.

Research has shown that during the recycling of plastic wastes especially during the melting process, a lot of volatile organic components (VOCs) and other substances are being emitted especially resulting from and by thermal degradation of plastic polymers (Yamashita *et al*., 2009). Environmental pollution is a significant problem for humanity because of considerable changes in eco system behaviour and the loss of biodiversity it is triggering and because it may be at the origin of different diseases and physiological disorders in humans.

According to Ait-Helal *et al*., (2014) ; Montoya *et al*., (2018) pollutants that impact air quality include volatile organic compounds (VOCs) which are introduced into the atmosphere through anthropogenic or biogenic activities and add to problems in the formation of tropospheric ozone and particles lower than 2.5 micrometers in various environments. Yamashita *et al*., (2009), stated that most of the VOCs and other substances emitted into the environment originated during polymer degradation from recycling operation.

VOCs as categorized by the World Health Organization (WHO) are compounds with a boiling point less than $250^{o}C$ measured at a standard atmospheric pressure of 101.3 and their physical and chemical properties and mean lifetime in the atmosphere ranges from a few minutes to several months and to years allows them to travel distances from the sources of emission and enters the body mainly by way of air or through the skin and causes symptoms that may lead to pathologies including asthma, atopic dermatitis and neurologic problems.

Some VOCs, like benzene, toluene, formaldehyde, 1,3 butadiene, vinyl chloride and tertrachloro ethylene are classified by the International Agency for Research in Cancer (IARC) in group I as carcinogenic to humans (Evuti, 2013; IARC, 2017).

They are rather inert lipophilic compounds capable of passing through biological membranes with a toxicity that basically depends on their biotransformation within the body (Barreto *et al*., 2009). Volatile organic compounds are an importance group of air pollutant because of their important role in the chemistry of the troposphere, their conditioning of the concentration of OH^- radical, the production of organic acids and the formation of photochemical oxidants (Filella and Penuelas, 2006).

VOCs like benzene, toluene, vinyl chloride, formaldehyde, tertrachloroethylene, styrene and furan have been shown to be harmful to human health, eco systems and the atmosphere (WHO, 2000).

Verma *et al*., (2015) reported that burning of plastics wastes increases the risk of heart diseases, aggravates respiratory ailments such as asthma and emphysema, rashes, nausea, headache and damages the nervous system, eyes and mucous membrane on the exposed population which are mainly industrial and factory workers occasioned by the releases of VOCs, heavy metals and other toxic substances.

Montero-Montoya stated that the lipophilic nature of VOCs in the body confers on them the capability to cross the mucous epithelia of the respiratory tract and the cell membranes in various organs like the kidney and liver. A study estimated the concentrations of VOCs, including benzene, toluene, styrene and furan with daily active patterns in a sample of school age children in an industrial area. This study was correlated with measurements of forced expiratory volume (FEV) and the force vital capacity (FVC) with the use of spirometric tests to identify respiratory capacity problems and it found that the increase in total exposure was significantly associated with a decrease in FEV. Consequently, they suggested that this type of exposure may be related to occurrence of asthma (Martins *et al*., 2012).

The environmental distribution of VOCs is a function of transport and source. The sources of VOCs are petroleum and natural gas extraction, petrochemical activities, burning of fossil fuels, chemical and industrial processes like manufacturing of paints, lubricants, adhesives, mining and plastic recycling (Montero-Montoya *et al*., 2018). The toxicity of the VOCs is a function of level of exposure, duration and composition.

In Scientific Equipment Development Institute, Akwuke-Enugu, where a plastic recycling unit is situated and functional, the need to draw the attention of the workers in the unit and the general environment where the recycling operation occurs to the exposure to volatile organic compounds and other substances that are usually emitted during polymer degradation as bye products in the recycling process and the dangers of these air pollutants to the health and the environment becomes very important and crucial.

Therefore, research was carried out to assess the levels of toxic volatile organic compounds and other substances in the air in the plastic recycling environment in Scientific Equipment Development Institute, Enugu and this was to ensure that the recycling operation does not adversely expose the workers and inhabitants in the environment and the office in general to levels of the air pollutants that would constitute public health concern.

II. Materials and Methods

Air were collected from within the plastic recycling unit in SEDI Enugu using air bags and syringes following a grab sampling approach (Yamashita *et al*., 2009). Selected VOCs (benzene, vinyl chloride tetrachloroethylene, formaldehyde, toluene, styrene and naphthalene) and other substances (furan and $PM_{2.5}$) were analyzed by thermal desorption gas chromatography and mass spectrometer (GC 6890 series/MS, 5973 network mass selective detector). Table 1 provides the analytical conditions for the assessment of the levels of the VOCs and substances.

Table 1: Analytical condition of GS/MS

Lustment	Condition
GC/MS	6890 series GC system, 5973 network mass selective detector.
Column	HP-1 methyl siloxane capillary 60.0. x 250um x 1.00μm
Carrier gas	He (1ml/min)
Column temperature	40°C, 4min (7°C/min) to 280°C, 10min
Detection mode	Scan

Quality Assurance

Prior to the sampling or calibration, all sampling tubes were conditioned at 330°C by passing pure nitrogen gas through the tubes at a flow rate of 100ml/min for 40min then checked in accordance with the same air pollutant analytical procedures to ensure that no target pollutants were present. The identification of VOCs and other substances were conducted by checking the retention time of individual air pollutants and their mass spectrum.

III. Results and Discussions

Table 2: Mean levels of toxic volatile organic compounds and other substances in the air in a plastic recycling unit in SEDI Enugu.

VOCs and other substances	Mean Concentration (μg/m^3)	WHO Permissible Limits
Benzene	1.71 ± 0.13	5
Vinyl chloride	231.74 ± 3.42	200
Tetrachloroethylene	14.16 ± 2.05	200
Furan	0.11 ± 0.06	0.3
Formaldehyde	0.41 ± 0.12	0.3
Toluene	101.08 ± 4.66	260
Styrene	20.77 ± 3.29	850
$PM_{2.5}$	28.25 ± 1.73	25
Naphthalene	4.11 ± 0.25	10

Benzene:

The maximum environmental exposure concentration in air for benzene for an individual is 5μg/m^3, this concentration is due to the hematological effect of benzene in humans. Result of Table 2 shows that the mean levels of benzene in air in the plastic recycling environment was 1.71 ± 0.13μg/m^3. Although the observed value was within the safe limit for benzene in air, it could still pose significant health risk to the exposed workers especially at consistent basis. The inability of the recycling unit to adequately sort out wastes in line with the unique uses of the plastics before they were made wastes could have resulted to this level of benzene in the air in the studied environment.

Montero Montoya *et al*., 2018 reported a higher value of 3.70μg/m^3 for benzene in outdoor exposure assessment in Tlaxcala, Mexico than what was reported for the VOC in this study.

According to Costa *et al*., (2016) exposure to benzene can cause hematological effects including aplastic anemia, with subsequent manifestation of acute myelogenous leukemia via the action of reactive metabolites. According the Verma *et al*., (2015) benzene is a known carcinogen and is released during plastic combustion.

Vinyl chloride

This particular VOC is naturally released during the degradation of plastic materials with ethylene chloride make up. The mean level of vinyl chloride in the air in the recycling environment was 231.74µg/m^3. Amongst the studied VOCs in the plastic recycling environment in SEDI-Enugu, the mean concentration of vinyl chloride in air was the highest. Proshad *et al.,* (2018) reported that prolong exposure to vinyl chloride at high doses causes chronic respiratory disorder and heart failure.

The level of vinyl chloride in the air in the studied environment was above the permissible limit of 200µg/m^3.

Tetrachloroethylene

Tetrachloroethylene is an important polymer with a very wide range of applications especially in household, automobile and engineering industries. The mean concentration of tetrachloro ethylene in the air in the plastic recycling environment was found to be 14.16 ± 2.05µg/m^3 and therefore within the recommended safe limit of 200µg/m^3 as established by WHO in 2000.

Yamashita *et al*., (2009) reported a lower value of 0.38µg/m^3 for vinyl chloride in the industrial area of Yokohama, Japan than reported for it in this study. According to Public Health Bulletin (2019), chronic exposure to tetrachloroethylene damages the kidney and central nervous system in humans and equally have reported evidences of carcinogenicity in animals.

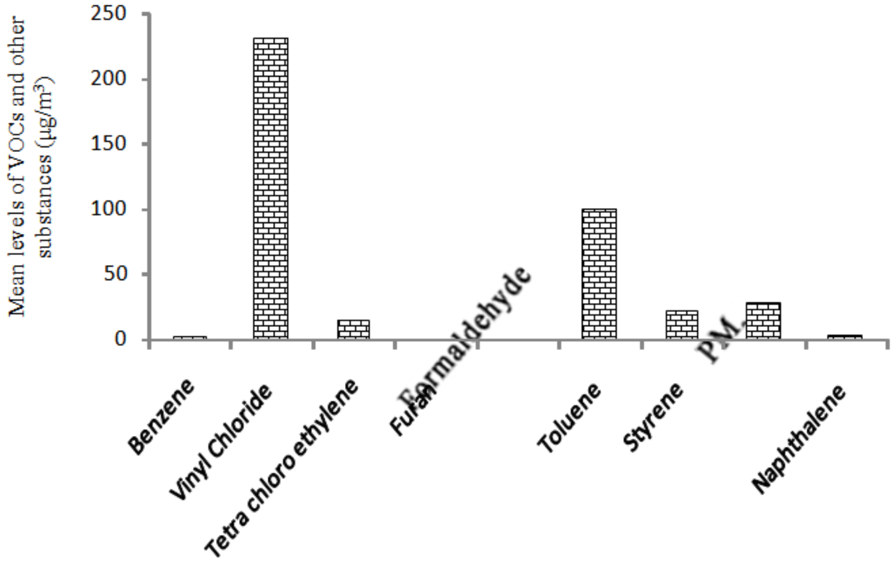

Fig. 1*: Bar chart representation of the mean levels of the volatile organic compounds and other substances in the air in a plastic recycling environment in SEDI-Enugu.*

Furan

Furan are toxic organic compounds which are colourless, highly flammable and with very low boiling points almost equal to room temperature.

According to Karademir *et al*., (2003) hazardous wastes (explosives, oxidizing, highly inflammable, infectious, and mutagenic) incinerations are responsible for the production of dioxin and furan. Furan exerts their toxicological effects via high affinity binding to a specific cellular protein known as aryl hydrocarbon receptor (AhR) (Schecter *et al*., 2006).

Recent pharmacokinetic studies have demonstrated that the half-life of furan is dose-dependent and varies with body composition (Karademir *et al*., 2003). Table 2 shows that the mean level of furan in the air in the studied environment was 0.11 ± 0.06µg/m^3 and therefore below its recommendable permissible limit.

In humans and other vertebrates furan have been shown to be risk factors for cancer, immune deficiency, reproduction and developmental abnormalities, central and peripheral nervous system pathology, endocrine disruption including diabetes and thyroid disorders, liver damage, skin rashes and loss of appetite (Schecter *et al.,* 2006).

Formaldehyde

Formaldehyde Table 2 shows that the mean level of formaldehyde in the air in the plastic recycling environment was 0.41 ± 0.12µg/m^3. The concentration of formaldehyde in the air in the studied environment was found to be above its recommended permissible limit in air.

Chronic exposure to formaldehyde results in sensory irritation of the eyes, nose and throat, lachrymation, sneezing, nausea and dyspnoea (Montero-Montoya, *et al*., 2018). According to WHO (2000) long term exposures to formaldehyde by industrial workers have been associated with nasal cancer. Sources of exposure to formaldehyde from the environment include oxidation of paint and vanishes incineration of waste materials and polymer degradation.

Toluene

Because of the structure of toluene, it easily volatilizes, thus can enter the body of organisms through many routes; the most common is inhalation followed by skin and at a lower percentage, orally through polluted water or food. Toxicokinetic studies in human and animals indicate that VOCs like benzene, toluene and styrene are distributed to highly vascular tissues rich in lipids like the brain, the bone marrow and the body and are slowly eliminated from the body (Montero-Montoya *et al*., 2018). The mean level of toluene in air in the recycling environment was 101.08 ± 4.66μg/m^3 and was observed to be below its recommended permissible limit in air.

Potential health impacts of exposure to toluene include eye, nose and throat irritation, headache, dizziness, feelings of intoxication, reduced memory attention and concentration Lee *et al*., (2002) reported a higher value of 139.35μg/m^3 for toluene in air in the industrial area of Kwei Chung in Hong Kong than reported for the VOC in this study.

Styrene

The result of Table 2 shows that the mean concentration of styrene in the air in the recycling environment was 20.77 ± 3.29μg/m^3. The level of styrene in the air as obtained from the study was within the recommended permissible limit of 850μg/m^3 set by WHO in 2000. Parra *et al*., (2008) reported a lower value of 2.15μg/m^3 for styrene in air in Pamoplona, Spain than what was obtained for the VOC in this study.

Montero Montoya *et al*., (2018) stated that the potential health impacts of exposure to styrene includes sensory irritation of the eyes, nose and throat and at high levels of exposure causes vomiting, tiredness, dizziness, hearing difficulties and psychological impairment.

$PM_{2.5}$

Particulate matter is one of the most dangerous forms of pollution as the size of the particles is so small that they get into the lung causing numerous adverse effects. $PM_{2.5}$ in particular are particles which are 2.5μm or less in diameter. Usually during plastic recycling, the thermal degradation of the plastic wastes results in releases of gases and particulates of matter. This particulate matter most times flies into or enters the eyes and noses of workers who fail to use protective devices during the recycling operation.

The mean level of particulate matter in the air in the recycling environment was 28.25 ± 1.73μg/m^3 and thus was found to be higher than the recommended permissible limit of 25μg/m^3 set by WHO in 2000.

Widiana *et al*., (2019) reported a lower value of 10.74μg/m^3 for $PM_{2.5}$ in the air around the municipal waste water treatment plant in Taoyuan in Taiwan that what was obtained for the air pollutant in this study.

According to Verma, (2016) long term exposure to $PM_{2.5}$ can result to impairments of vision, hearing difficulties, and lung diseases.

Napthalene

The result of Table 2 shows that the mean concentration of naphthalene in the air in the studied recycling environment was 4.11 ± 0.25μg/m^3. The value obtained for naphthalene in this study was found to be within the recommended permissible limit set for it in air as provided by WHO in 2000.

High dosage exposure to naphthalene in humans can result to haemolytic anemia and respiratory tract infections while also cancer related diseases have been reported in long term animal studies (Public Health England, 2019).

IV. Conclusion

Toxic violatile organic compounds (such as benzene, vinyl chloride, tetrachloroethylene, formaldehyde, toluene, styrene and naphthalene) and toxic substances like furan and $PM_{2.5}$ were found present in the air in the studied environment where plastic recycling is usually carried out. The levels of the studied pollutants such as vinyl chloride, formaldehyde and $PM_{2.5}$ were above their recommended threshold limits in the studied environment, however, the other studied toxic air pollutants such as, furan, toluene, styrene and napthalene were within their respective permissible limits.

Indeed the study concludes that although plastic recycling operation is an economic venture with a lot of profit taking, the environmental and health impact associated with the emission of volatile organic compounds and other toxic substances are equally huge. Undue and prolonged exposure to some of the studied air pollutants especially at toxic levels (levels that are above the permissible limits) can result to life-long diseases and death.

Adequate provision must be made to ensure that the emitted VOCs and other substances arising from plastic recycling operation should be absorbed and converted to less harmful forms before being released into the environment in order to safeguard and equally preserve the health of those living and working within such an environment.

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