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TOXICITY POTENTIAL OF THE EMITTED AEROSOLS FROM OPEN BURNING OF SCRAP TYRES

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ABSTRACT

Open Burning of Scrap Tyres (OBST) has been identified as a key source of air pollutants. However, OBST has been widely and indiscriminately practiced in Nigerian communities with less attention to its environmental impacts. Aerosols of diameter less than 10 μm ($PM_{2.5}$ and PM_{10}) emitted from OBST were considered. In this study, twenty (20) types of tyre representing five from each of bicycle, motorcycle, car and truck category were investigated. The mass concentration of the aerosols was measured using GT 331 Aerosol Mass Monitor. The most breached limits are ASHRAE and WHO limits of 50 μg/m^3 for PM_{10} where 3 motorcycle, car and truck tyre samples have the TP values above unity. The least breached is NAAQS standard for $PM_{2.5}$. An assessment of the toxicity potential levels of these aerosols establishes that OBST may have adverse effects on human health and environment.

Keywords: particulate matter; open burning; scrap tyres; toxicity potential; health; environment.

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1. INTRODUCTION

According to U.S.EPA (1997), approximately 250 million automobile tyres are scrapped every year in the United States, posing a serious disposal problem. In the past, environmentalists have focused on solid and hazardous waste issues related to scrap tyre disposal. Much information has already been reported regarding the comparative merits of disposal alternatives such as land filling, recycling, and burning for fuel in minimizing scrap tyres and maximizing recycle markets. One way of removing tyres from the waste stream is disposal in valuable landfill space. Due to the properties of scrap tyres such as non-biodegradability, bulkiness and variation in durability, scrap tyres are difficult to dispose. Potential fire hazard which emanates from unregulated stockpiles of scrap tyres contributes to environmental, health, and safety problem (U.S. Scrap tyre markets, 2003).

Scrap tyres are land filled and stockpiled in tyre dumps for the purpose of obtaining energy when burnt and re-used in whole tyre applications. The disposal process and air emissions from the open burning of scrap tyres have been the environmental problems associated with scrap tyres. Large toxic residues and hazardous gaseous emissions are generated as a result of thick black toxic smoke which emanates from open burning of scrap tyres. According to Hassanien (2007), the toxic residues and gaseous emissions from burning tyres may lead to environmental harm and pose serious threats to public health and safety. Also, the toxic residue may contaminate both groundwater and surface water. Stored scrap tyres in open areas do retain rainwater, thereby turning to the breeding ground for mosquitoes and other insects (Anf and Emad*,* 2014).

Among all the air pollutants in ambient air, PM has greater effects on people than any other pollutants (Pope and Dockery, 2006). The major constituents of PM are sulphate, nitrates ammonia, sodium chloride, carbon, mineral dust and water. PM consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in air. Particles are identified according to their aerodynamic diameters as either PM_{10} or $PM_{2.5}$ (aerodynamic diameters equal to or smaller than 10 and 2.5 µm respectively).

When people breathe particulate–laden air, particles with a diameter greater than 10 micrometers (ten millionths of a meter) are usually stripped by the nose. Smaller particulates can enter the respiratory system and are often called “inhalable” or “inspirable” (Wangki, et *al., 2014*). Particles that are smaller than 10 µm but larger than 2.5 µm can generally get as far as the larynx. Smaller particles can penetrate into the lungs and are often called “respirable”. The inhalation of dust containing silicon oxides is responsible for heart disease called Silicosis (WBCSD, 2008). Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases and also lung cancer. In developing countries, exposure to pollutants from the indoor combustion of solid fuels, open tyre fires or traditional stoves increases the risk of acute lower respiratory infections and associated mortality among young children (Wangki *et al.,* 2014). Particulate matter has recently become an issue of increasing importance in pollution studies due to its noticeable effects on human health. Various studies on air pollution effects on health have indicated a strong relationship between air pollutant concentrations and observed health effects. There is also strong evidence that fine particles (dp < 2.5µm) play an important role in the observed health effects (Lewtas, 2007; Sonibare and Jimoda, 2009). Coarse particles (2.5 µm < dp < 10 µm) are effectively removed in the upper part of respiratory track while fine particles (dp < 2.5 µm) are deposited on the bronchi walls in the bronchi tree.

The studies on Toxicity Potential (TP) of PM from OBST have predicated upon growing human health concern about PM inhalation (Pope, 2000; Anf and Emad, 2014; Abbas *et al*., 2007; Otto *et al*., 2007; Sacks *et al*., 2010). Particulate matter whether by intrinsic or extrinsic toxicities have been linked to severe health hazards due to the hypothetical mechanism of the adverse effects of particulate through metal-generated free radicals (Guinée and Heijungs, 1993; Gilmour, 1996; Lu *et al*., 2008). Therefore, this study was carried out to investigate the potential emission of particulate pollutants ($PM_{2.5}$ and PM_{10}) from the combustion of scrap tyres and their possible impacts on human health and environment.

2. MATERIALS AND METHODS

2.1 Collection of Tyre Samples

Scrap tyre samples were collected from tyre repairing workshops. Twenty different types and qualities of tyre were selected representing five each from bicycle, motorcycle, car and truck category. The reason for choosing these vehicle types as representative for this study is that light vehicles (passenger cars, motorcycles and bicycles) are dominantly used within towns and cities while heavy vehicles (trucks) are used to transport goods between Northern and Southern regions of Nigeria. The tyre samples were washed, cleaned and shade-dried to remove any adhered foreign materials and shredded to uniform sizes (Shakya et al., 2008; Lemieux and Ryan, 1993).

2.2 Experimental Set-up

Fifty (50 g) gram of each of the samples was weighed and cut into fine pieces for easy burning. The monitoring of aerosol mass concentration was carried out in a laboratory scale combustion chamber. The combustion chamber has two parts; the cylindrical and a detachable inverted funnel-like part with a conductive tube, 2 cm in diameter attached directly to the top of the cylinder. The combustion chamber has a diameter of 15.5 cm and a height of 46 cm (the length of the cylinder and the inverted funnel are 18 cm and 28 cm respectively). The volume of the chamber is 4000 cm^3. The combustion chamber was equipped with sampling equipment. Before burning, the combustion chamber was purged by scrubbing and air was blown into it using air blower. This was done to make sure the chamber was free of any contaminant (Shakya et al., 2008; Lemieux and Ryan, 1993). Burning of each sample was carried out for 20 mins. In the experimental process, ambient air was introduced into the chamber through the pores at the lower part of the chamber to maintain pressure equilibrium within the chamber (Lemieux and Ryan, 1993). The smoke released from the combustion chamber was taken from the flue through a conductive tube which was attached to the top of the chamber (Lemieux and Ryan, 1993).

2.3 Sampling of Aerosols

Particulate matter of diameters 10 µm and 2.5 µm (PM_{10} and $PM_{2.5}$) were investigated in this study due to their links with morbidity and mortality of individuals (WHO, 2008) and hence categorized as inhalable and respirable particles. Aerosol concentration mass measurements were taken using a freshly calibrated GT 331 Aerosol Mass Monitor, which is a portable, handheld and battery operated equipment manufactured by Met One Instruments Inc., Washington. The monitor is capable of measuring five ranges of particulates: PM_1, $PM_{2.5}$, PM_7, PM_{10} and TSP with a concentration range of 0–1 mg/m^3 (and resolution of 0.1 $\mu g/m^3$). The monitor employs the principle of light scattering to size individual particle that passes through the laser optical system. Information from the manufacturer indicates that during factory calibration of the monitor, its mass concentration reading has been checked against a Beta Attenuation Monitor (BAM) which is a reference standard method of quantifying mass concentration, hence no correction of the output concentrations is required (Met One Instruments, 2001). The monitor has a sampling cycle of 5 mins after which the LCD display allows a real-time viewing of the measured values (Fakinle *et al.,* 2013; Met One Instruments, 2001). The measured concentrations values from 20-min averaging period were extrapolated to 24-hr averaging period for comparison as most of the set statutory limits used are for the daily basis. The extrapolation of these values was computed using an atmospheric stability formula in equation 1 (Al-Smadi *et al.,* 2009; Fakinle *et al.,* 2013).

$$C_1 = C_o x F \quad [1]$$

2.4 Estimation of the Toxicity Potential of the Emitted Aerosols

The Toxicity Potential (TP) of aerosols was obtained from ratio of measured ambient PM concentration to the standard limits of ambient concentration (Fakinle *et al.,* 2013; Sonibare *et al.,* 2005). The standard limits (Table 1) used were United States Environmental Protection Agency (USEPA), World Health Organization (WHO), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and National Ambient Air Quality Standards (NAAQS). Because of the proximity of residential houses, workshops and offices to the plume path, the probability of human health effects exists. Pollutant with TP greater than unity is hazardous to human health and environment (Fakinle *et al*., 2013; Owoade *et al*., 2009). The TP of the pollutants was computed using equation 3 (Jimoda *et al.,* 2017):

$$TP_{\text{i}} = \frac{C_{i(t)}}{SL_i(t)} \quad [3]$$

where C_o is the concentration at the averaging period t_o

C_1 is the concentration at the averaging period t_1

F is the factor to convert from the averaging period t_1 to the averaging period t_o

$$F = \left(\frac{t_1}{t_0}\right)^n \quad [2]$$

n = 0.28, the stability dependent exponent Fakinle *et al.,* 2013).

where TP represents the toxicity potential of pollutant ‘i’

C_i is the extrapolated concentration of pollutant ‘i’ at time ‘t’

SL_i is the standard concentration limit of pollutant ‘i’ at time ‘t’

‘i’ = $PM_{2.5}$ and PM_{10}.

Table 1: 24-hr Standard Limits of Particulate Matter

Particle Type		WHO (2006) (μg/m^3)	ASHRAE (2010) (μg/m^3)	NAAQS (μg/m^3)
$PM_{2.5}$	35	25	15	65
PM_{10}	150	50	50	150

3. RESULTS AND DISCUSSION

3.1 Concentrations of the Emitted Aerosols

The 20-mins measured and 24-hour extrapolated concentrations of emitted aerosols from open burning of scrap tyres were presented in Table 2 (bicycle tyres), Table 3 (motorcycle tyres), Table 4 (car tyres) and Table 5 (truck tyres). For bicycle tyre samples considered, the 20-mins measured values are 19.10–79.40 μg/m^3 and 78.50–428.50 μg/m^3 for $PM_{2.5}$ and PM_{10} (Table 2) which on extrapolation to 24-hour averaging period became 5.77–23.97 μg/m^3 and 23.70–129.38 μg/m^3, respectively. For motorcycle tyre samples, the measured particulates were 26.00–120.60 μg/m^3 and 134.50–284.50 μg/m^3 which on 24-hour averaging period extrapolation became 7.85–36.41 μg/m^3 and 40.61–85.90 μg/m^3 for $PM_{2.5}$ and PM_{10}, respectively (Table 3).

For car tyre samples considered, the 20-mins measured values are 18.40–85.20 μg/m^3 and 102.40–546.80 μg/m^3 for $PM_{2.5}$ and PM_{10} (Table 4) which on extrapolation to 24-hour averaging period became 5.56–25.73 μg/m^3 and 30.92–165.10 μg/m^3, respectively. For motorcycle tyre samples, the measured particulates were 24.60–245.10 μg/m^3 and 137.00–528.50 μg/m^3 which on 24-hour averaging period extrapolation became 7.43–74.01 μg/m^3 and 41.37–159.58 μg/m^3 for $PM_{2.5}$ and PM_{10}, respectively (Table 5). The observed concentrations of the aerosols from different samples and qualities were found to vary quantitatively despite using same mass and condition. It infers therefore that the emission levels were dependent on the material compositions of the tyres (Shakya *et al.,* 2008). However, the concentration levels of the aerosols to be emitted through complete burning of the representative tyre samples would proportionately increase with their respective scrap tyre masses.

Table 2: Measured and Extrapolated Concentrations of Aerosols from Open Burning of Scrap Bicycle Tyres

Sample ID	Measured Concentration (μg/m^3) 20 min		Extrapolated Concentration (μg/m^3) 24 hr	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
BT A	19.10	78.50	5.77	23.70
BT B	79.40	97.30	23.97	29.38
BT C	46.80	116.80	14.13	35.27
BT D	63.20	118.40	19.08	35.75
BT E	59.70	428.50	18.03	129.38

Table 3: Measured and Extrapolated Concentrations of Aerosols from Open Burning of Scrap Motorcycle Tyres

Sample ID	Measured Concentration (µg/m³) 20 min		Extrapolated Concentration (µg/m³) 24 hr	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
MT A	26.00	207.10	7.85	62.53
MT B	102.10	284.50	30.83	85.90
MT C	120.60	253.30	36.41	76.48
MT D	109.50	160.60	33.06	48.49
MT E	75.30	134.50	22.74	40.61

Table 4: Measured and Extrapolated Concentrations of Aerosols from Open Burning of Scrap Car Tyres

Sample ID	Measured Concentration (µg/m³) 20 min		Extrapolated Concentration (µg/m³) 24 hr	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
CT A	18.40	102.40	5.56	30.92
CT B	85.20	172.10	25.73	51.97
CT C	65.10	546.80	19.66	165.10
CT D	56.20	152.30	16.97	45.99
CT E	69.30	528.50	20.92	159.58

Table 5: Measured and Extrapolated Concentrations of Aerosols from Open Burning of Scrap Truck Tyres

Sample ID	Measured Concentration (µg/m³) 20 min		Extrapolated Concentration (µg/m³) 24 hr	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
TT A	24.60	200.40	7.43	60.51
TT B	104.10	272.60	31.40	82.31
TT C	245.10	146.80	74.01	44.33
TT D	132.20	137.00	33.31	41.37
TT E	67.30	528.50	20.32	159.58

For $PM_{2.5}$, none of the investigated bicycle tyres exceeded the trio of USEPA, WHO and NAAQS standard limits. Out of five bicycle tyre samples considered, three breached ASHRAE standard. Also, only MT C exceeded USEPA statutory limit while all MT samples investigated were below NAAQS standard. Two of the tyre samples were below WHO limit. ASHRAE standard was breached by 80 % of the motorcycle tyre samples considered. None of the car tyre samples exceeded the duo of USEPA and NAAQS standard limits. WHO limit was violated by CT B while 80 % of the CT samples considered breached ASHRAE 24 hr standard. In TT samples, USEPA limit was breached in 20 % of the TT samples. WHO limit was violated by TT B, TT C and TT D while four of the truck (TT B, TT C, TT D and TT E) tyre samples considered breached ASHRAE 24 hr standard. Only TT C exceeded NAAQS standard limit.

For PM_{10}, none of the BT and MT samples investigated exceeded the standard limits of both USEPA and NAAQS. However, CT C, CT E and TT E breached USEPA and NAAQS limits.

For WHO and ASHRAE limits, 50 % of the tyre samples breached the standard limits of 50 µg/m^3.

3.2 Toxicity Potential

Tables 6-9 show the computed TPs obtained when the statutory limits given in Table 1 were used. For bicycle tyre samples (Table 6), the computed USEPA, WHO, ASHRAE and NAAQS TP levels for $PM_{2.5}$ were 0.16–0.68, 0.23-0.96, 0.38–1.60 and 0.09–0.37, respectively. USEPA and NAAQS TPs are within the range of 0.16–0.86 while those of WHO and ASHRAE are within the range of 0.47–2.59 for PM_{10}.

Table 6: 24 hrs Toxicity Potential of Aerosols from Bicycle Tyre Samples

Sample ID	$PM_{2.5}$				PM_{10}			
	USEPA	WHO	ASHRAE	NAAQS	USEPA	WHO	ASHRAE	NAAQS
BT A	0.16	0.23	0.38	0.09	0.16	0.47	0.47	0.16
BT B	0.68	0.96	1.60	0.37	0.20	0.59	0.59	0.20
BT C	0.40	0.57	0.94	0.22	0.24	0.71	0.71	0.24
BT D	0.55	0.76	1.27	0.29	0.24	0.72	0.72	0.24
BT E	0.52	0.72	1.20	0.28	0.86	2.59	2.59	0.86

As given in Table 7, the $PM_{2.5}$ TPs range for USEPA, WHO, ASHRAE and NAAQS are 0.16-0.74, 0.22–1.03, 0.37–1.72 and 0.09– 0.40, respectively for motorcycle tyre samples. USEPA and NAAQS TPs are within the range of 0.27–0.57 while those of WHO and ASHRAE are within the range of 0.81–1.72 for PM_{10}.

Table 7: 24 hrs Toxicity Potential of Aerosols from Motorcycle Tyre Samples

Sample ID	$PM_{2.5}$				PM_{10}			
	USEPA	WHO	ASHRAE	NAAQS	USEPA	WHO	ASHRAE	NAAQS
MT A	0.16	0.22	0.37	0.09	0.42	1.25	1.25	0.42
MT B	0.74	1.03	1.72	0.40	0.57	1.72	1.72	0.57
MT C	0.56	0.79	1.31	0.30	0.51	1.53	1.53	0.51
MT D	0.48	0.68	1.13	0.26	0.32	0.97	0.97	0.32
MT E	0.60	0.84	1.39	0.32	0.27	0.81	0.81	0.27

The computed USEPA, WHO, ASHRAE and NAAQS TP levels for $PM_{2.5}$ for car tyre samples (Table 8) were 0.22–1.04, 0.31-1.46, 0.52–2.43 and 0.12–0.56, respectively. USEPA and NAAQS TPs are within the range of 0.21–1.10 while those of WHO and ASHRAE are within the range of 0.62–3.30 for PM_{10}.

Table 8: 24 hrs Toxicity Potential of Aerosols from Car Tyre Samples

Sample ID	$PM_{2.5}$				PM_{10}			
	USEPA	WHO	ASHRAE	NAAQS	USEPA	WHO	ASHRAE	NAAQS
CT A	0.22	0.31	0.52	0.12	0.21	0.62	0.62	0.21
CT B	0.88	1.23	2.06	0.47	0.35	1.04	1.04	0.35
CT C	1.04	1.46	2.43	0.56	1.10	3.30	3.30	1.10
CT D	0.94	1.32	2.20	0.51	0.31	0.92	0.92	0.31
CT E	0.65	0.91	1.52	0.35	1.06	3.19	3.19	1.06

As summarized in Table 9, the $PM_{2.5}$ TPs range for USEPA, WHO, ASHRAE and NAAQS are 0.21–2.11, 0.30–2.96, 0.50–4.93 and 0.11–1.14, respectively for truck tyre samples. USEPA and NAAQS TPs are within the range of 0.28–1.06 while those of WHO and ASHRAE are within the range of 0.83–3.19 for PM_{10}.

Table 9: 24 hrs Toxicity Potential of Aerosols from Truck Tyre Samples

Sample ID	$PM_{2.5}$				PM_{10}			
	USEPA	WHO	ASHRAE	NAAQS	USEPA	WHO	ASHRAE	NAAQS
TT A	0.21	0.30	0.50	0.11	0.40	1.21	1.21	0.40
TT B	0.90	1.26	2.09	0.48	0.55	1.65	1.65	0.55
TT C	2.11	2.96	4.93	1.14	0.30	0.89	0.89	0.30
TT D	1.12	1.57	2.62	0.60	0.28	0.83	0.83	0.28
TT E	0.58	0.81	1.35	0.31	1.06	3.19	3.19	1.06

Toxicity potential value greater than unity indicates that such concentration has a great tendency of causing harm to human health and environment and therefore should be avoided. The most breached limits are ASHRAE and WHO limits of 50 $\mu g/m^3$ for PM_{10} where 3 motorcycle, car and truck tyre samples have the TP values above unity. These are being followed by

ASHRAE standard for $PM_{2.5}$ and WHO standard for $PM_{2.5}$. The least breached is NAAQS standard for $PM_{2.5}$.

4. CONCLUSION

This study has shown that OBST could contribute to elevation in concentration of aerosols in environment. People could be exposed to significant concentration levels of aerosols due to OBST in the environment as the toxicity potential levels were above unity in some of the tyre samples investigated. The most breached limits are ASHRAE and WHO limits of 50 μg/m^3 for PM_{10} where 3 motorcycle, car and truck tyre samples have the TP values above unity. These are being followed by ASHRAE standard for $PM_{2.5}$ and WHO standard for $PM_{2.5}$. The least breached is NAAQS standard for $PM_{2.5}$. Toxicity potential value of any pollutant greater than unity indicates that such concentration has a great tendency of causing harm to people in sensitive categories (young, aged people and people with respiratory diseases) and pose threats to environment. Hence, scrap tyre management practices which involve reduction, reuse, recycling, energy recovery and proper disposal are recommended to be adopted along with strict compliance with both national and international laws and regulations.

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