INFLUENCE OF TEMPERATURE AND RELATIVE HUMIDITY ON TOTAL VOLATILE ORGANIC COMPOUND (TVOC) EMISSION CONCENTRATION IN PARKED VEHICLES

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ABSTRACT

This study considered the influence of two atmospheric variables (temperature and relative humidity) on total volatile organic compound (TVOC) pollutant emission concentration in parked vehicles at Ignatius Ajuru University of Education, Rumuolumeni. One hundred parked vehicles (50 parked vehicles under shade and 50 parked vehicles in the sun) were selected for the study. TVOC monitor was placed right inside each of the selected parked vehicles to measure its TVOC emission concentration, atmospheric variables (temperature and relative humidity) for a period of three months. The readings were taken between the hours of 12pm to 3pm, Nigerian time. This was done for vehicles parked under shade and vehicles parked in the sun. The measured TVOC concentration for vehicles parked under shade showed a positive correlation of 0.451 with temperature and a negative correlation of -0.087 with relative humidity, while that of the parked vehicles in the sun, the measured TVOC concentration showed a weak negative correlation of -0.264 with temperature and a weak positive correlation of 0.333 with relative humidity for the period under study. The measured TVOC concentrations of the selected vehicles parked under shade and in the sun with the following values 0.56 mg/m^3, 0.604mg/m^3, 0.698mg/m^3, 0.711mg/m^3, 0.732mg/m^3, 0.740mg/m^3, and 0.882mg/m^3 for the period under study were higher than the occupational exposure limits of 3mg/m^3 to 5mg/m^3. This study shows that shades did not play any major influence in the reduction of emission concentration of TVOC in Parked vehicles. Hence cross ventilation of vehicles should be considered by vehicle users in order to prevent any hazardous effects due to prolong exposure to high build-up of TVOC concentration in vehicles.

Keywords: Influence, Temperature, Relative humidity, TVOC concentration, Vehicles

1.1 INTRODUCTION

The harmful effect of air pollution on the environment and human's health has been on the increase as a result of human activities, mostly in developing countries and Nigeria in particular, where the effects of air pollution has no diminishing rate (Igbokwe *et al*, 2015, Ede and Edokpa, 2015, Edokpa *et al*, 2019; Ede and Edokpa 2017). According to Ait-Helal *et al (*2014), anthropogenic or biogenic activities are continually introducing pollutants such as Volatile Organic Compounds (VOCs) that blend with other pollutant to impact the atmospheric boundary layer. More so, in our daily activities, we are always in contact with some items like disinfectant, semi-conducting materials, petroleum products, paint solvent, adhesives, and many other products that emits volatile organic compounds. Also, in our long distant journeys, we often spend hours inside vehicles, which sometimes translates into considerable exposure to high TVOC concentration emitted by the vehicles. According to Klepeis *et al* (2001) commuters on average, spend 5.5% which is about 79 minutes of their time on a daily basis in automobiles. Fedoruk & Kerger (2003), "the emission of volatile organic compounds (VOCs) from automobile cabin materials is one of the main causes of poor vehicular air quality''

Exposure to VOCS, particularly in new vehicles could result to sick car syndrome (SCS) (Kim *et al*, 2011). A number of studies have reported that among the anthropogenic sources of VOCs vehicles were the major contributor to VOC emission (Cui *et al*, 2015).

1.2 TOTAL VOLATILE ORGANIC COMPOUND

VOCs is a combination of a large number of heterogeneous organic compounds such as aliphatic and aromatic hydrocarbons, alcohols, aldehydes, ketones, esters and halogenated compounds, which are highly volatile (Talapatra and Srivastava, 2011). According to Goldstein and Galbally (2007), "scientific interest in atmospheric VOCs originated in Los Angeles in the 1950s, when Haagen-Smit first recognized the importance of anthropogenic organic compounds in atmospheric chemistry''. In scientific literature, "VOCs are organic chemical compounds which can evaporate easily under normal conditions of temperature and pressure''. "Volatile organic compounds are generally referred to as highly reactive or toxic organics emitted by both human made and natural sources due to their high volatility at normal atmospheric condition'' (Godish *et al*, 2015). A group of World Health Organisation experts in consensus, adopted internationally recognized definition of (VOCs) (WHO, 1989). "It was opined that "volatile organic compounds should include volatile organic compounds within a defined interval of boiling points 50-100^{0}C sampled by absorption and analysed by Gas Chromatography (GC) or Liquid Chromatography (CL)''(WHO, 1989). VOCs can be classified into groups based on volatility--very volatile organic compounds with boiling points between less than 0^{o}c and 100^{o}c, volatile organic compounds with boiling points between 100^{o}c and 240^{o}c, and semi-volatile organic compounds having boiling points between 240 and 400^{o}c (WHO, 1989). The group of VOCs is often treated as one entity and is then called TVOC (Total Volatile Organic Compound).

1. 2.1 SOURCES OF TVOC

Sources of TVOC is generally divided into two--Natural and Anthropogenic sources. According to Guenther (2006), tropical and extra-tropical forests are the largest sources of volatile organic compound globally.

Natural sources (Biogenic): Natural sources of TVOC include wildfire, emission by vegetation, wetlands, and VOCs emitted by animals or microorganisms.

Anthropogenic (man-made) sources: Anthropogenic sources of TVOC are the TVOC that emanate from human activities such as transportation, manufacturing industries, oil refining storage, oil and gas, waste deposits, electricity generation, and household products and residential sector. Industries and vehicle transportation are the two primary sources of anthropogenic emissions that have the biggest impact on the global atmosphere. Zhang, *et al* (2008); Faber, *et al (*2013) reported that materials such as plastics, sealants, paints, leather, fabrics, carpets, an foam used to design the compartment and interior of vehicles are largely responsible for vehicles' indoor pollution. In a study by Brodzik *et al* (2014), they noted that the sealing materials and adhesives around the sunroof in many newly manufactured vehicles could increase the emissions aldehyde concentration values of the range 23.0 -1110 μg/m^3 and a mean value of 80μg/m. Yoshida *et al* (2006) conducted a study using 50 new cars and found the measured in-cabin formaldehyde concentration to be between 17-61μg/m$^{3.}$ A research finding by You *et al* (2007) showed that the correlation between the total concentration of volatile organic compound (TVOC) and the airflow in the cabin is a function of air velocity in the surroundings. "When the air velocity increases from 0.15 to 0.7mls, the airflow rate increases from 0.15 to 67h^{-1}, whereas the TVOC concentration decrease from 1780 to 120.0μg/m^3'' (You *et al*, 2007). Xu, *et al* (2006) reported that vehicles with leather interior emit higher VOCs concentrations than vehicles designed with fabrics, and equally higher in newly manufactured vehicles than old vehicles. Fedoruk and Kerger (2003) found TVOC levels in a

6-month old vehicles in the USA were 400-500 μg/m^3 under warm conditions, but increases to at least 5-fold under extreme heat conditions. Xiong *et al* (2015) theoretically derived a correlation equation between the in-cabin VOC concentration and temperature. This correlation equation is given by equation (**$*_1$)** $\frac{lnC_a}{T^{0.75}} = \frac{C_{1-C_2}}{T}$ **…………………………. (**1)

Where Ca is the pollutant concentration in the vehicle cabin in μg/m^3, T is the air temperature in the vehicle cabin, C_1 and C_2 are positive constants, which are independent of temperature and only related to the physical and chemical properties of the material-pollutant combinations.

1.2.2 EFFECTS OF TVOC

Health Effect: The quality of the air human beings breath can adversely affect human's health. The major route of exposure to VOCs is through inhalation. Among the health effects of VOCs, the most common issue is their toxic or carcinogenic effects (Ramirez, 2012). A good number of studies have shown that long term exposure to VOCs poses serious health effects (Rumcher *et al.,* 2004). Health effects associated with VOCs could either be short or long term---short term health effects are nose and throat discomfort, headache, sleeplessness, fatigue and dizziness, allergic skin reaction, while leukaemia, loss of coordination, anaemia, and cancer are long term effects (Kim *et al.,* 2002; Kerbachi *et al.,* 2006). The level of harmful effect of organic compounds depends on the nature of the organic compound. These compounds vary from highly toxic to those with no known health effect. Furthermore, the health problems associated VOCs depends on the concentration, specific composition, and the length of time of exposure to VOCS.

Climate Change: Emission of VOC may have adverse environmental effects on the local, regional and the climate. TVOC contributes considerably to the development and growth of aerosols which modify the micro-climate condition of any domain directly through absorbing both incoming and outgoing solar/infrared radiation. TVOCs reacts with nitrogen oxides on hot summer day (Plocoste *et al*, 2018), this results in the formation of atmospheric ozone and particles of smaller size below 2.5μm in big cities (Lee *et al.*, 2002). "Biogenic sources of VOCs emissions are easily influenced by climate change as well as playing important role in climate, increasing greenhouse gas concentrations and formation of aerosols in the atmosphere"(Constable *et al.*,1999).

VOCs from both mobile and stationary sources are defined as ozone precursor (Pitts & Pitts, 2012) and they affect climate change indirectly**.**

Regional Impacts: The formation of photochemical smog is largely attributed to VOCs. Photochemical smog is formed when VOCs react with nitrogen oxides in the presence of sunlight producing a brown haze over cities and this phenomenon is more common in summer because of abundant sunlight during this period of the year (USEPA, 2004).

1.3 MATERIALS AND METHOD

Study Area: The vehicles used for this study were parked vehicles at Ignatius Ajuru University of Education campus, Rumuolumeni community in Obio-Akpor Local Government Area of Rivers State, Nigeria. The study area (Ignatius Ajuru University of Education) has a geographical coordinates of latitude 4° 48' 0.6343" N and longitude 6° 55' 52.9835" E. The climatic condition of the study area is tropical monsoon. This geographical location is marked by long period of Rainy season, usually from March to November and a short period of dry season, usually from December to February. These long period of rainfall and short dry seasons of study location could be attributed to its nearness to rivers and a network of creeks with large water bodies. "The university campus is bounded by creeks to the North, Eagle Cement Manufacturing Company and other companies and private establishments like Master Energy to the South, residential area to the East and creeks to the West". Figure 1 is the satellite map of the study area.

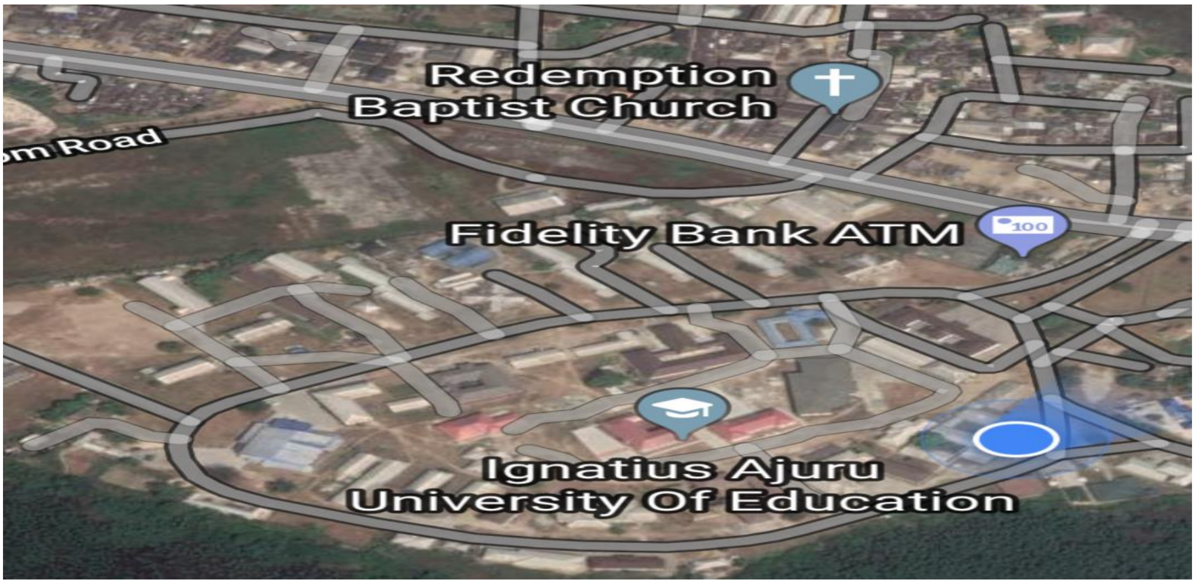

Figure1: Satellite View of Ignatius Ajuru University Campus and the Adjoining Residential Area

1.3.1 MATERIALS

The materials/instrument employed in this study include TVOC monitoring device, 100 parked vehicles, and a stop watch.

TVOC Monitor: The TVOC monitor is a portable hand held chargeable volatile organic compound (VOC) device used to measure accurately a variety of air synthetic indicators, the total amount of natural and synthetic volatiles organic compounds that cause most odours, and dust particles less than 2.5 microns.

Stop Watch: This is a handheld timepiece employed in measuring the time intervals.

One hundred parked vehicles (50 parked vehicles under shade and 50 parked vehicles in the sun) were selected for the study. TVOC monitor was placed right inside each of the selected parked vehicles to measure its TVOC emission concentration, atmospheric variables (temperature and relative humidity) for a duration of three months. The readings were taken after five minutes, this was done for both the vehicles parked under shade and vehicles parked in the sun. The measuring time was from 12pm to 3pm, Nigerian time. Correlations between the measured emitted TVOC concentration and the measured atmospheric variables were also determined.

1.4 RESULTS AND DISCUSSION

Figures 2, 3, 4, and 5 are scatter plots showing the trends between the mmeasured TVOC concentration and atmospheric variables (temperature and relative humidity) for vehicles parked uunder shade and in the sun respectively.

Scatter Plot: Scatter plots enable us to determine the relationship between the measured variables, outliers and the appropriate statistical tool to be employed in statistical analysis.

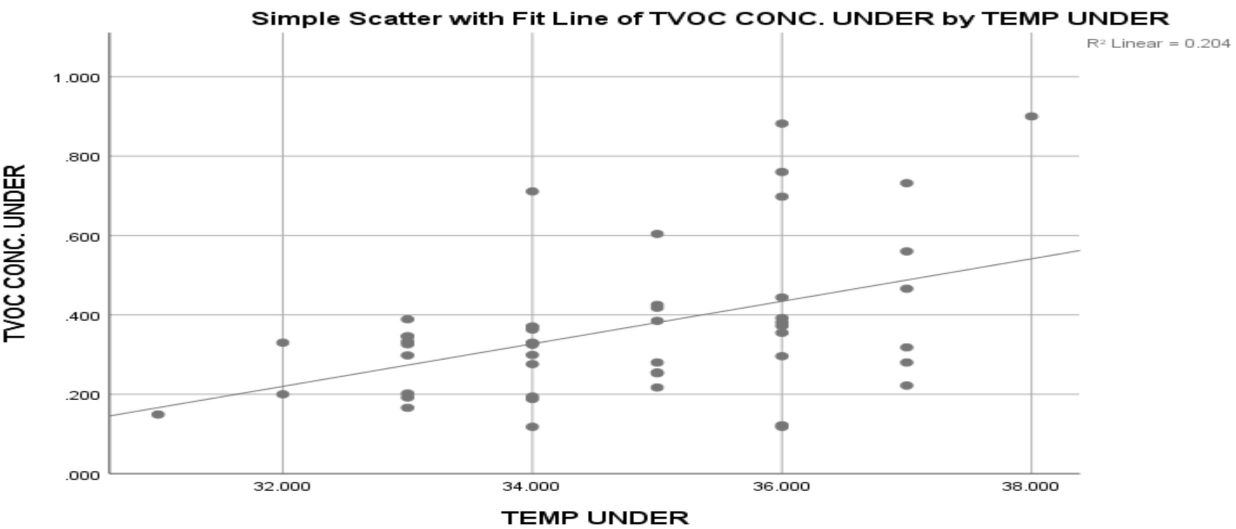

Figure2: Scatter Plot of Measured TVOC Concentration Vs Temperature of vehicles Parked Under Shade

Figure 2 shows a positive linear relationship between the measured TVOC concentration and temperature for vehicles parked under shade.

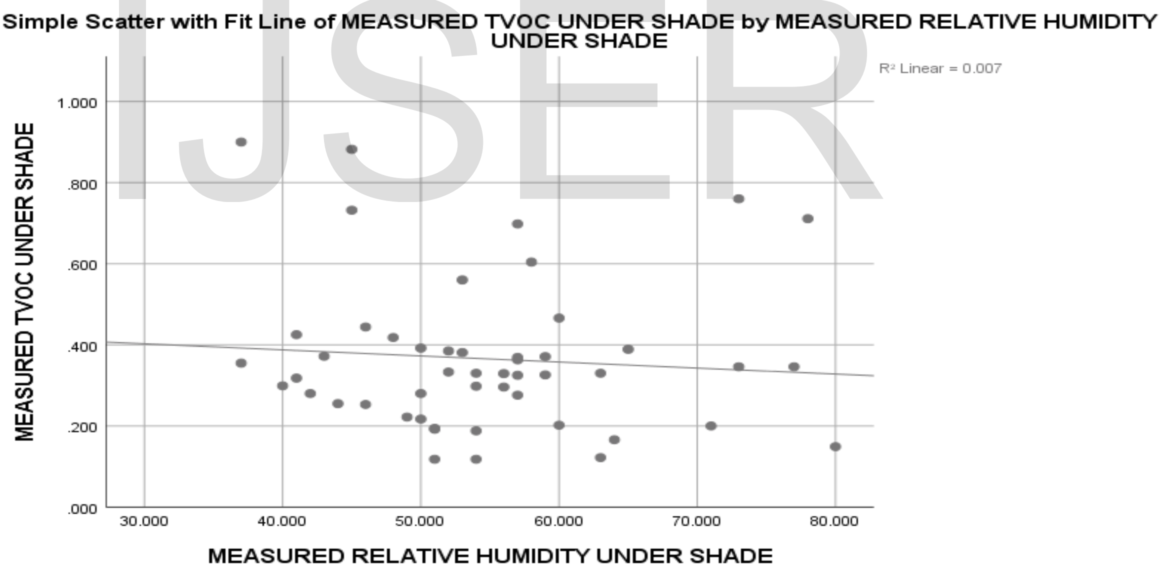

Figure 3: Scatter Plot of Measured TVOC Concentration Vs Relative Humidity of Vehicles Parked Under Shade

In figure 3, the relationship between the two variables (TVOC concentration and relative humidity) for vehicles parked under shade is a negative linear relationship.

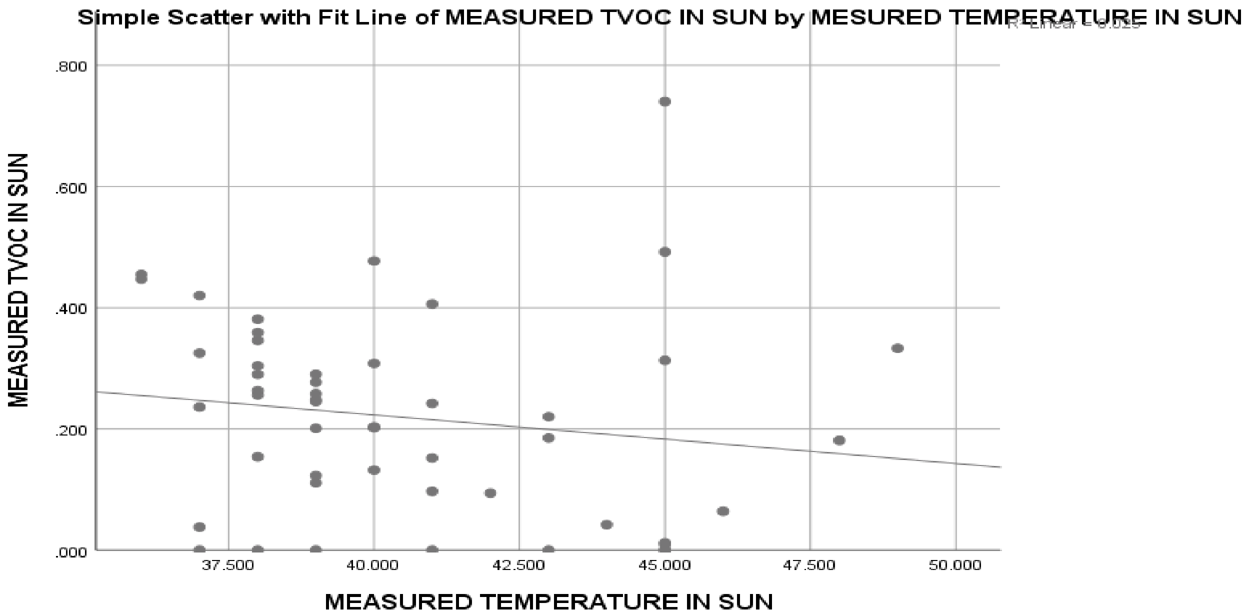

Figure 4: Scatter Plot of Measured TVOC Concentration Vs Temperature of Vehicles Parked in the Sun

Figure 4 also shows a fairly negative linear relationship between the measured TVOC concentration and Temperature for vehicles parked in the sun.

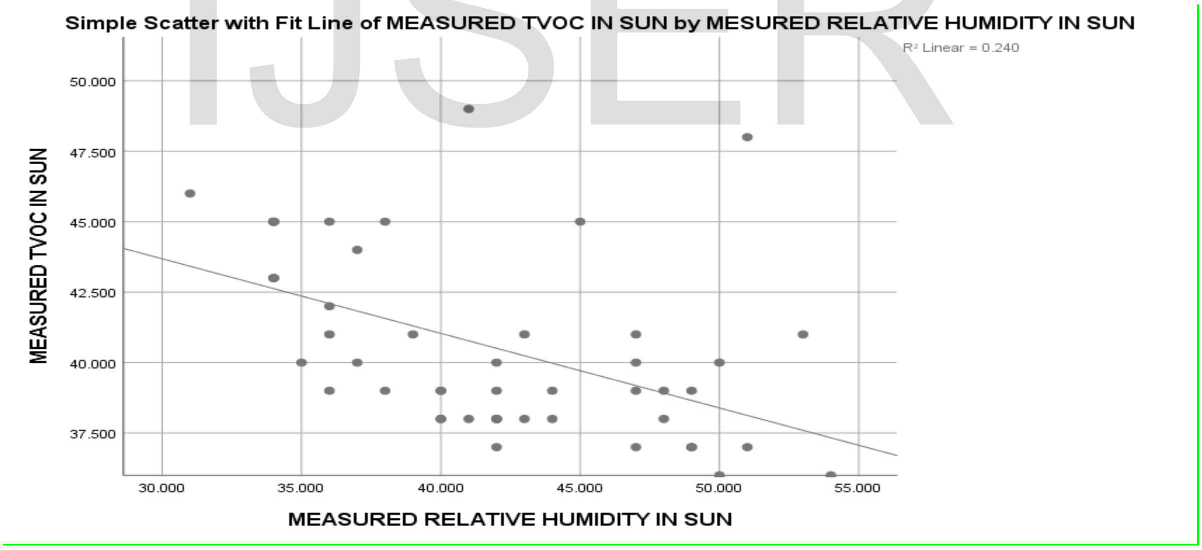

Figure 5: Scatter Plot of Measured TVOC Concentration Vs Relative Humidity of Parked Vehicles in the Sun

Figure 5 indicates a strong negative linear relationship between the measured TVOC concentration and relative humidity for vehicles parked in the sun.

Atmospheric Variables: The mean temperature (40.56^{o}C) of the vehicles parked in the sun was higher than the mean temperature (34.72^{o}C) of the vehicles parked under shade for the period under study. This difference in temperature could be due to direct exposure of the vehicles to solar radiation. For relative humidity, the mean relative humidity (54.66%) measure in parked vehicles under shade for the period under study was higher than the mean relative humidity (41.80%) measured in vehicles parked in the sun. This difference in the mean of relative humidity could be attributed to reduction in the rate of evaporation in vehicles parked under shade.

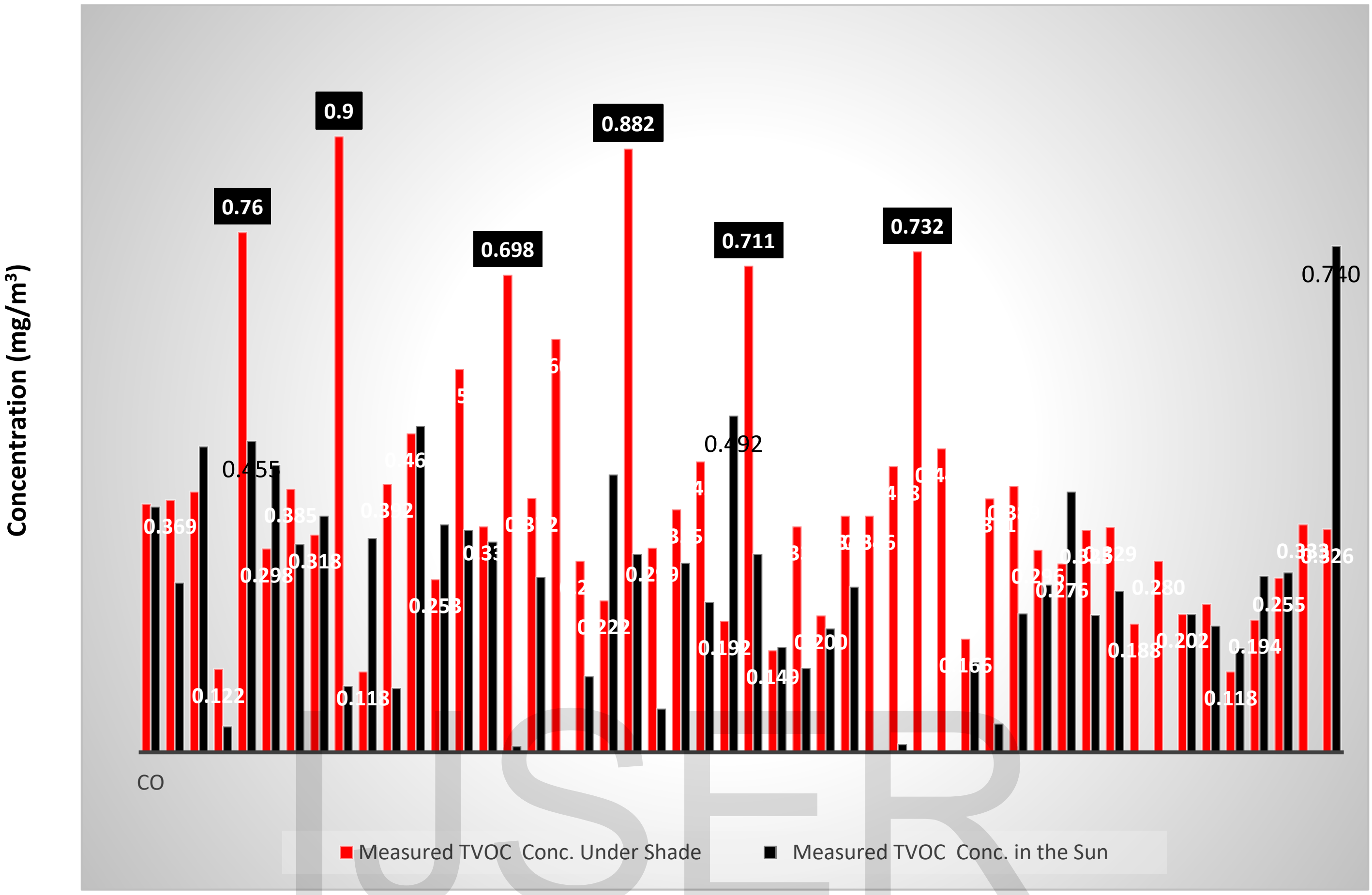

Figure 6: Graphical Representation of the Measured TVOC Concentration of Vehicles parked under Shade and in the Sun

Figure 6 is a bar chart showing the measured emitted TVOC concentration of the selected vehicles for the period under study. The red colour bars represent TVOC concentration emitted by the parked vehicles under shade, while the black colour bars represent TVOC concentration emitted by vehicles parked in the sun. More so, in figure 6 greater number of vehicles parked under shade emit more TVOC concentration than those vehicles parked in the sun.

Comparing the difference between the mean of the measured TVOC concentrations in vehicles parked under shade and the vehicles parked in the sun, the mean TVOC concentration (0.3657mg/m^3) of vehicles parked under shade for the period under study was higher than TVOC concentration (0.2186) of the vehicles parked in the sun. This could be attributed to the fact that vehicles parked under shade have higher relative humidity than vehicles parked in the sun.

1.4.1 CORRELATION ANALYSES

Correlation analyses for vehicles parked under shade: The measured TVOC Correlation and atmospheric variables (temperature and relative humidity) showed a positive correlation of 0.451 between the measured TVOC concentration and temperature, and a very weak negative correlation of -0.087 between the measured TVOC concentration and relative humidity for the period under study.

Correlation analyses for vehicles parked in the sun: The measured TVOC concentration also showed a weak negative correlation of -0.264 with temperature and a weak positive correlation of 0.333 with relative humidity for the period under study.

1.5 CONCLUSION

Generally, TVOC has no federally enforceable standards in non-industrial setting (USEPA, 2021). In this study, the measured TVOC concentrations of the selected vehicles parked under shade and in the sun with the following values 0.56 mg/m^3, 0.604mg/m^3, 0.698mg/m^3, 0.711mg/m^3, 0.732mg/m^3, 0.740mg/m^3, and 0.882mg/m^3 for the period under study were higher than the occupational exposure limits of 3mg/m^3 to 5mg/m^3 stated by Advanced Solutions Nederlands B.V (2020). Finally, the finding of this study shows that shades does not play any major influence in the reduction of emission concentration of TVOC in Parked vehicles. Hence the need for cross ventilation of vehicles by vehicle users in order to prevent any hazardous effects from prolong exposure to high build-up of TVOC concentration in vehicles.

REFERENCES

[1] Ait-Helal, .W, Borbon, .A, Sauvage, .S, De Gouw, .J.A, Colomb, .A, Gros, .V, Freute, .l.F, Crippa, .M, Afif .C, Baltensperger, .U, Beekmann, .M, Doussin, .J.F, Durand-Jolibois, .R, Fronval, .I, Grand, .N, Leonardis, .T, Lopez, .M, Michoud, .V, Miet, .K, Perrier, .S, Prévôt ASH, Schneider .J, Siour .G, Zapf .P, & Locoge, .N .(2014). Volatile and intermediate volatility organic compounds in suburban Paris: Variability, origin and importance for SOA formation. *Atmos. Chem. Phys., 14*:10439–10464.

[2] Brodzik, .K, Faber, .J, & Golda – Kopek .A. (2014). In – vehicle VOCs composition of unconditioned newly produced cars. *J. Environ Sci.* 26: 1052 – 1061.

[3] Constable, J., Guenther, A. Schimel, D., & Monsoon, R. (1999). Modelling changes in VOC emission in response to climate change in the continental United States. *Global change Biology*, 791 – 806.

[4] Cui, H.Y., Chen, W,H., Dai, W., Liu, H., Wang, X.M.,& He, K.B.(2015).Source apportionment of $PM_{2.5}$ in Guangzhou combining observation data analysis and chemical transport model simulation, *Atmos. Environ., 116*, 262 – 271,

[5] Derwent, R.G (1995). Sources, distribution and fates of VOCs in the atmosphere issues in *Environmental Science and Technology 4*: 1-16.

[6] Ede, P.N. & Edokpa, O.D. (2017). "Satellite determination of particulate load over Port Harcourt during Black soot incidents. *Journal of Atmospheric Pollution"5*(2), 55-61.

[7] Ede, P.N. & Edokpa, O.D. (2015). Regional Air quality of the Nigeria's Niger Delta. *Open Journal of Air Pollution, 4*:7-15.

[8] Edokpa, O.D. & Ede, P. N. (2019). Preliminary Air quality Index Estimates of particulates concentration in Port Harcourt during soot incidents International *Journal Innovative Students in Science and Engineering* Faber, J. Brodzik, K., Golda, K.A. &

[9] Lomankiewiez, D. (2013). Air pollution in new vehicles as a result of VOC emissions from interior material *Journal of Environmental Studies, 22*, 1701 – 1709.

[10] Fedoruk, M.J., & Kerger, B.D... (2003). Measurement of violate organic compounds inside automobiles. *Journal Expo Anal. Environ. Epidemiology, 13*, 31 - 41.

[11] Godish, T., Davis, W.T, & Fu, J.S. (2015). Air Quality, 5th Ed. CRC Press: Boca Raton, FL 175.

[12] Goldstein, A. H. and I. E. Galbally (2007). "Known and unknown organic constituents in the earth's atmosphere."*Environmental Science & Technology 41*(5): 1514-1521.

[13] Guenther, A., Karl, T., Harley, P., WIedinmyer, C., Palmer, P. (2006). Estimates of Global terrestrial Isoprene emissions using MEGAN (Model of emissions of gases and aerosols: from nature). *Atmospheric Chemistry and physical and physics European Geosci. Union 6*, 3181- 3210.

[14] Igbokwe, J.O., Nwufo, O.C., Ononungbo, C, (2015). The Health and environment implication of thermal power Generation in Nigeria. *International Journal of Engineering and Modern Technology, 1(*18), 115 – 124.

[15] Kerbachi, R., Boughedaoui, M., Bounoue, L and keddam, M. (2006). Ambient air pollution by aromatic hydrocarbons in Algiers. *Atmospheric environment, 40*, 3995 – 4003.

[16] Kim, K. W., Lee, B. H., Kim, S., Kim, Kim, H.J., Yolu, J. K. & Yoo, S.E. (2011). Reduction of VOC emission from natural flours filled biodegradable bio-composite for autombilities interior. *Journal Harvard Mat., 187,* 37 – 43.

[17] Kim, Y.M., Harrad, S. and Harrison R.M. (2002) levels and sources of personal inhalation exposure to VOCs. *Environ Science Technology* 36, 405 – 5410.

[18] Klepeis N.K, Nelson we, Robinson J.P, Tsany A.M, Switzer, P., Beliar J.V, Hern S.C& Engelmann, W.H.(2001).The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. *Journal of expo Anal Environmental Epidemiol .2001*: 11: 231 – 252.

[19] Lee, S.C., Chiu, M.Y., Ho, K.F., Zou, S.C., & Wang X.M. (2002). Volatile organic compounds (VOCs) in Urban Atmosphere of Hong Kong. *Chemosphere 48*(3), 375 – 382.

[20] Pitts, B.F., & Pitts, J. (2012). Atmospheric chemistry of Tropospheric ozone formation. Scientific and Regulatrory implications. *Air & Waste* 1091 – 1100.

[21] Plocoste, .T, Dorville, .J.F, Monjoly, .S, Jacoby-Koaly, .S & André, .M .(2018). Assessment of nitrogen oxides and ground level ozone behaviour in a dense air quality station network: Case study in the Lesser Antilles Arc. *J. of the Air & Waste Management Association*, *68*(12).

[22] Ramirez, N. (2012). Chronic risk assessment of exposure to volatile organic compounds in the atmosphere near the largest Mediterranean industrial site. *Environment International* 200-209.

[23] Rumcher, V., Spickett, J., Bulsara, M., Philip, M., and Stocks, S. (2004). Association of domestic exposure to volatile organic compounds with Asthma in young children. Thorax 59,746 – 751.

[24] Shao, M., Huang, D., Gu, D., Lu, S., Chang. C., & Wang. J. (2011). Estimate of anthropogenic halocarbon emission based on measured ratio relative to CO in the Pearl River Delta region. China, *Atmos. Chem. phys*., 11, 5011 – 5025.

[25] Suh, H. H., Bahadiri, .T., Vallarino, J., & Spengler, J.D. (2000). Criteria for air pollutants and toxic air pollutants. *Environmental Health perspective 108*(4) 625 – 633.

[26] Talapatra, A. & Srivastava, A.(2011). "Ambient air non-methane volatile organic compound (NMVOC) study initiatives in India– A Review."*Journal of Environmental Protection* 2: 21.

[27] USEPA.(2004). Photochemical smog—what it means for us. https://www.epa.sa.gov.au/files/8238 _info_photosmog.pdf.

[28] WHO.(1989). Indoor air quality: Organic pollutants. EURO Reports and studies No. 111. Copenhagen, WHO Reg. *Office for Europe*.

[29] Xiong, J., Yang T., Tan J., Li L., & Ge, .Y, (2015). Characterization of VOC Emission from Materials in Vehicular Environment at Varied Temperatures: Correlation Development and Validation. Plos One.;10:e0140081. doi: 10.1371/journal.pone.0140081.

[30] XU, J. Xhang, J .S, Grunewald, J. Zhao, J.H, Plagge R, & Quali .A. (2006). A study on the similarities between water vapour and VOC diffusion in porous media by a dual chamber method. *Clean soil Air water 37* 444-453.

[31] Yoshida, T., Matsunaga, I., Tomioka, K & Kumaga, T. (2006). Interior air pollution in automotive cabins by volatile organic compounds diffusing from interior materials II influence of manufacturer, specifications and usage status on air pollution and estimation of air pollution levels in initial phases of delivery as a new car. *Indoor Built Environ*; 15: 445-462.

[32] You, K.W, Ge Y.S., Hu, B., Ning Z.W, zhao S.T, & zhang, Y .N (2007). Measurement of in – vehicle volatile organic compounds under static conditions. *Journal of Environmental Science* IT: 1208 – 1213.

[33] Zhang,Y.H, SU, H., Zhong, L.J.(2008). Regional ozone pollution and observation – based approach for analysing ozone – precursor relationship during the pride – Prad 2004 campaign Atmos, 2008, 42, 6203 – 6218.

[34]Zhu, Y., Eiguren – Fernandez .A, Hinds, W.C, & Miguel' A.H. (2007). In-cabin commuter exposure to ultrafine particles on Los Angeles freeways. *Environmental science Technology*. 41(7): 2138 – 2145.