Full Paper

MEASUREMENT OF AMBIENT CONCENTRATION OF NO_2 IN OBAFEMI AWOLOWO UNIVERSITY CAMPUS USING PASSIVE SAMPLERS

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ABSTRACT

This study measured ambient concentration of NO_2 in Obafemi Awolowo University (OAU) campus using locally fabricated passive samplers designed based on the principles of mass transfer and diffusion. Two types of samplers studied were tubes of varying lengths (2cm and 7cm) at three locations for different sampling durations. A mixture of sodium hydroxide (NaOH) and sodium iodide (NaI) in Methanol was used as absorbent for NO_2. Samplers loaded with absorbents were exposed for durations of 1, 2, 3 and 4 weeks. Withdrawn samplers from sampling sites at the end of respective sampling periods were analysed in the laboratory using modified Griess-Saltzman method. Optical absorbance values of coloured solutions formed were measured with UV/VIS Spectrophotometer at 540nm. Results showed that the two sampler types were effective for sampling and both gave acceptable estimates in the 1 week sampling duration. The ambient air concentration of NO_2 in Site 1 (7.0ppb-12.4ppb) is highest followed by Site 2 (4.2ppb-10.6ppb) and then Site 3 (0.2ppb-4.1ppb). All these values are below the limits set by the Federal Ministry of Environment which is 40ppb-60ppb.

Keywords: *NO_2, Passive Sampler, Diffusion, Absorption, Spectrophotometry*

1. INTRODUCTION

Air quality assessment of an environment is an indication of the wholesomeness based on the quantity of polluting gases and particulates it contains (Microsoft Encarta, 2009). Recent events such as the mysterious fog that engulfed some parts of Lagos on October 12, 2005 (Sonibare and Jimoda, 2009) have turned air pollution into a subject of national interest, though it received little attention in the past (Dinari et al., 2007). Some of the methods that have been used for measuring air quality are active sampling method, automatic method and remote optical/long path-analyzers. Developing networks of instruments which sample based on these methods, which would show the distribution of the pollutants, is encumbered by high cost (Hopke and Markowitz, 2002).

Passive sampling method can be utilized as a relatively inexpensive method for measuring ambient air quality. Passive sampling uses the technique of analyte molecules free flow from the sampled medium to a receiving phase in a sampling device, as a result of a difference between the chemical potentials of the analyte in the two media. The net flow of analyte molecules from one medium to the other continues until equilibrium is established in the system or until the sampling period is stopped (Vrana et al., 2005). Analytes are trapped or retained in a suitable medium within the passive sampler, known as a reference or receiving phase. This can be a solvent, chemical reagent or a porous adsorbent. The air samples are collected with a small tube-like device that relies on the diffusion of compounds to a collection surface or sorbent. The diffusion barrier across the tube confers a constant predetermined effective flow rate that is only slightly affected by temperature and unaffected by pressure (or altitude). Because of their low cost, it is relatively affordable to put samplers at multiple sites within a study region.

In this study, the concentration of nitrogen dioxide (NO_2) in the ambient air of Obafemi Awolowo University, Ile-Ife, Nigeria was measured as a representative fraction of the air quality. Nitrogen oxides (NO_x) are key urban pollutants linked to different respiratory ailments (EPA, 2004). NO_x are formed by processes that involve burning of fuel at high temperatures. Nitric oxide (NO) produced in the combustion process is readily oxidized in the atmosphere to produce NO_2.

$$2NO_{(g)} + O_{2(g)} \rightarrow 2NO_{2(g)} \qquad (1)$$

Because sources of NO_2 are partly anthropogenic, a community's exposure is highly influenced by its proximity to roads and industries. NO_2 also acts as a tracer for some noxious pollutants such as hydrocarbons, carbon monoxide, and surface level ozone because it is a product of combustion (EPA, 1997). At high levels, NO_2 causes inflammation of the airways. Long term exposure to NO_2 may affect lung function, causes respiratory symptoms and also enhances the response to allergens in sensitive individuals. High levels of NO_2 can have adverse effect on vegetation, including leaf or needle damage and reduced growth. Deposition of pollutants derived from NO_2 emissions can contribute to acidification and/or eutrophication of sensitive habitats leading to loss of biodiversity, often at locations far removed from the original emissions.

The use of passive diffusion tubes for measuring NO_2 was first introduced by Palmes and co-workers (Palmes et al., 1976). Though they were initially used for workplace monitoring, they have now been adapted for air quality management (Atkins and Lee, 1995; Kirby et al., 1998; Shooter et al., 1997; Kirby et al., 2000). The passive diffusion tube has been used for many years to measure outdoor concentrations of NO_2 across rural (Hopke and Markowitz op. cit.) and urban (Campbell et al., 1994) national networks, and for more local scale concentration variations (Hewitt, 1991; Van Reeuwijk et al., 1998). Despite this, there are ongoing investigations on this type of passive sampler for the purpose of improvement. In a study (Plaisance et al., 2002), several biases resulting from meteorological parameters are identified, specifically overestimation caused by wind turbulence. In this work, a protective shelter (originally proposed by Hangartner and Burri, 1987) was suggested as well as a corrective formula arrived at by experiments at various wind speeds. A protective sheath was used in this study to lessen the effect of these biases.

Theoretically, if a suitable absorbing agent is used, the concentration of a gas can be kept at zero at a point using diffusion theory. Thus, gas will always flow to that point. With this property, the flow of a sample can be constricted to a tube, having one end open to the gas sample and the other end closed off with suitable absorbing agent present at the closed end. The absorbing agent used for NO_2 in this research is a mixture of sodium hydroxide (NaOH) and sodium iodide (NaI) in Methanol which was used for the IGAC/DEBITS AFRICA (IDAF) research initiative (IDAF, 2004). When NO_2 in the atmosphere diffuses into the sampler, it reacts with the absorbent and gets converted to nitrite.

$$NO_{2(g)} + 3I^- \rightarrow NO_2^- + I_3^- \qquad (2)$$

2. THEORY OF PASSIVE SAMPLING

Passive samplers work based on the principle of diffusion. Pollutants flowing freely in air are directed towards the absorbent contained in the passive sampler. This occurs because of concentration difference between the interior of the sampler and the immediate surroundings. At a stage, a steady state is developed in which continuous absorption by the absorbent in the sampler is balanced by a diffusive flow of pollutants from the surrounding air towards the sampler as shown in Figure 1. The basic principle of diffusion theory that governs this process is Fick's Law. According to Fick's Law (Coulson et al., 2004), the diffusive flow of molecules is driven by a concentration difference. The mass flow per unit area j (g/cm^{2}s) at a certain point in space is directed perpendicular to planes of equal concentration and points towards the area of lower concentration. This mass flow per unit area is directly proportional to the difference in concentration ΔC (g/cm^3) per unit distance Δx (cm)

$$j = -D \frac{\Delta C}{\Delta x} \qquad (3)$$

where D is diffusion coefficient in cm^2/s.

The absorbent of the sampler is then later analyzed with a suitable method to determine the concentration of pollutant absorbed.

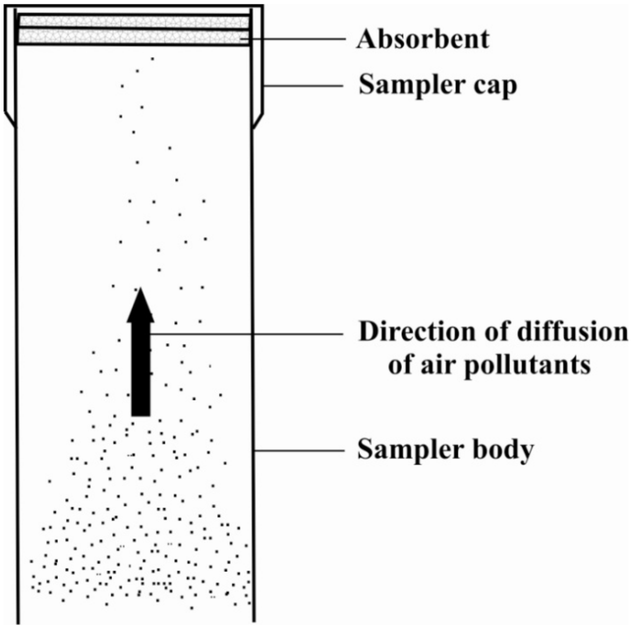

Figure 1: Schematic diagram of passive sampler

3. MATERIALS AND METHODS

3.1. Study Area and Period

The study area for the research is Obafemi Awolowo University (OAU) campus, Ile-Ife, Osun State, Nigeria. The map of the area is shown in Figure 2. The OAU campus is located in South-Western Nigeria on longitude 4°40'E and latitude 7°30'N. The topography of the area is such that it lies between 800 and 900 feet above sea level. OAU is an academic institution situated in the tropical climate region. The diurnal temperature variation is usually very small and the relative humidity is very high. Temperatures rise as high as 30°C during dry season and the rainfall average is between 1143mm and 1524mm. Sources of air pollution in OAU include gaseous emissions from motor vehicles and motorcycles, burning of waste at the dumping sites, emissions from laboratory, dust, pesticides and other chemicals used in agriculture and burning of domestic fuel.

Three sites were chosen for the study. These sites were selected specially in areas where people are mostly found and hence, exposed to long-term effect of the air quality. Site 1 is New Bukateria Complex located in the western end of the campus. Site 2 is OAU Staff Quarters in the residential area. Site 3 is Chemical Engineering Department in the academic area.

Samplers were deployed in Site 3 between December 2009 and January 2010; whereas, the period of sampling for Site 1 and Site 2 was January 2010 to February 2010.

3.2 Reagents Used

Chemicals used for this research include N-1-Naphthyl Ethylene Diamine Dihydrochloride (NEDA), Phosphoric acid (H_3PO_4), Sodium Nitrite ($NaNO_2$), Sodium Hydroxide (NaOH), Sodium Iodide (NaI), Methanol and Sulfanilamide.

3.3 Passive Samplers Used

The samplers (Figure 3) consist of cylindrical acrylic tubes of industrial grade with internal diameter of 1.4 cm, two acrylic rings, filter paper and two plastic meshes. Depending on the type of sampler of interest, tubes were cut into 2cm (sampler type 1) or 7cm

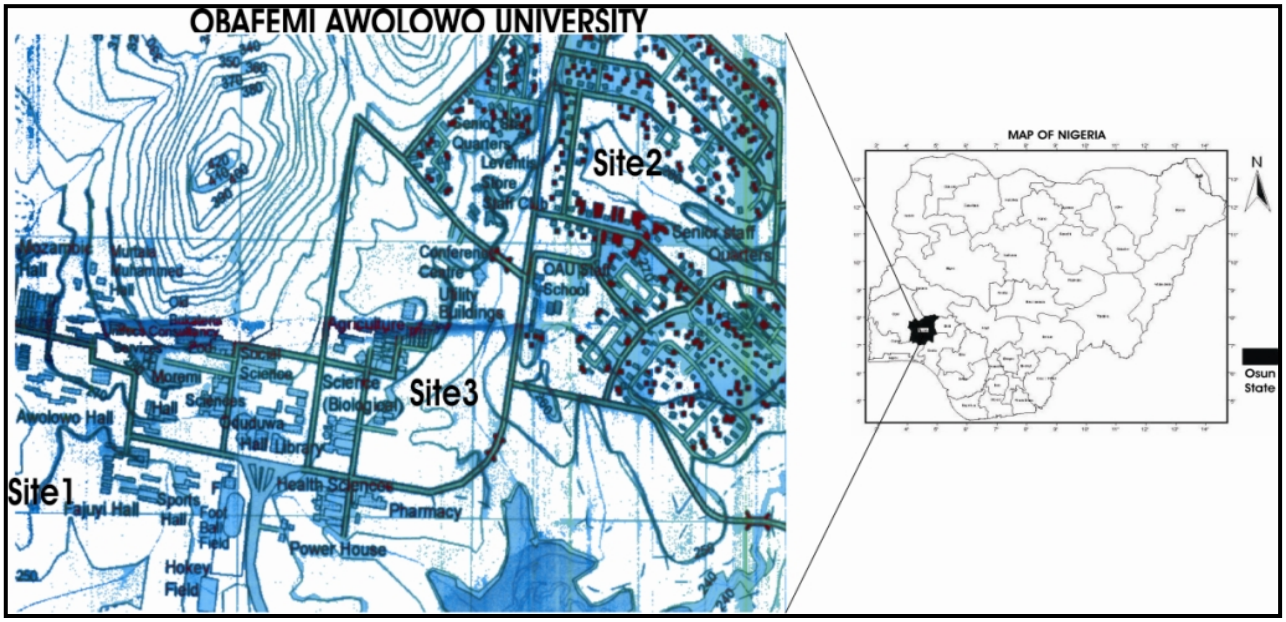

Figure 2: Map of study area

(sampler type 2). This model was chosen for the following reasons: possibility of reuse of all parts (except filter papers), minimization of turbulence, free-flow of air through the inlet, screening of particles by the presence of plastic meshes, simplicity of sampler model and cost effectiveness.

The absorbent used in impregnating the filter paper contained 0.5g NaOH and 4g NaI in Methanol (wetting agent). The open end of the tube was sealed before and after sampling. After placing the sampler on site, the seal from the end without impregnated filter was removed. Field blanks were also suspended, but without removal of the seal. Each sampler was vertically positioned with open end pointing downwards. The samplers were mounted on a stand (1.5m high) and covered with a sheath to prevent them from direct insolation and rain. After the sampling period was concluded the previously removed seal was replaced.

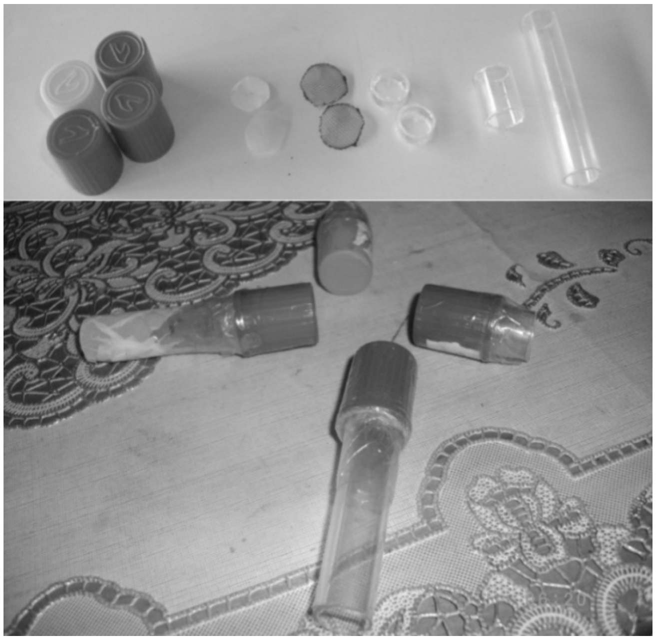

Figure 3: Passive sampler and components

3.4 Calibration Plot

The method of analysis to determine the amount of NO_2 captured by the tubes involves measuring the absorbance of sulphanilamide-NEDA solution that reacts with NO_2 using the UV/VIS Spectrophotometer. To determine the concentration of NO_2 relative to absorbance, a calibration plot was prepared using known amounts of NO_2^- in solution. Six standard solutions of $NaNO_2$ were prepared. Precise volumes of 1.4ml were drawn from each into its own test tube and 1.6ml of sulfanilamide-NEDA solution was added to each of the test tubes. The absorbance for each standard solution was measured using the spectrophotometer after allowing the pink solution to stay for 15 minutes for complete colour development (Targa et al., 2007). Absorbance values were plotted against concentration of NO_2^- and simple linear regression was applied. The curve gave r^2 value of 0.9976 and an intercept of 0.024002.

3.5 Post-deployment Analysis

The modified Griess-Saltzman method (Lodge, 1989) was used for the post-deployment analysis. This method is also a modification of that proposed by Atkins (Atkins et al., 1986). 0.35g of NEDA was put into a 250ml volumetric flask and filled with distilled water to its line. 5g of sulfanilamide was put into another 250ml volumetric flask, then, 15ml phosphoric acid was added and filled to the mark with distilled water. The entire content of the volumetric flask containing the sulfanilamide solution was poured into a 500ml Erlenmeyer flask. 35.7ml of the NEDA solution was added to the 500ml flask. This gave 1:7 ratio of the NEDA /Sulfanilamide solution. The well mixed combined solution was kept in a dark bottle to avoid penetration of UV light and capped with a stopper.

At the end of sampling periods, the samplers were withdrawn from the sites and analysed. The filter paper was carefully recovered from the cap of each passive sampler, placed in a test tube and covered. 1.4ml distilled water was added to each test tube, after which 1.6ml of the combined sulfanilamide-NEDA solution was added to give a total of 3ml (capacity of the cuvette provided with the spectrophotometer). The pink coloration observed gave indications of NEDA dye reacting with NO_2 captured by the tubes during exposure. The test tubes were covered and allowed to stay for 15 minutes. This was done for all exposed samplers and also field blanks. Each blank extract was poured in a cuvette and taken as reference, while the absorbance reading of the corresponding exposed sampler extract poured in the second cuvette was taken. Libra S21 model of UV/VIS Spectrophotometer produced by Biochrom Limited was used for absorbance measurements. Before use, the UV/VIS Spectrophotometer was calibrated and set at wavelength of 540nm. This wavelength was kept constant.

3.6 Computation Algorithm

3.6.1 Concentration of Nitrite in sampler

The absorbance measurement was used in determining the concentration of nitrite absorbed in filter paper by interpolation on the calibration curve. From the calibration plot,

$$Ab = 0.59238 \times C_{Ni} + 0.024002 \qquad (4)$$

where Ab is absorbance reading and C_{Ni} is concentration of nitrite (µg/ml).

3.6.2. Mass of nitrite

The mass of nitrite collected on the filter paper is calculated thus:

$$M_{Ni} = C_{Ni} \times V \qquad (5)$$

where M_{Ni} is mass of nitrite (µg), C_{Ni} is concentration of nitrite (µg/ml) and V is volume of extract (3ml).

3.6.3 Calculation of diffusion coefficient of NO_2 at ambient temperature

According to Massman (Massman, 1998),

$$D = D_{STP} \times \left(\frac{T}{T_{STP}}\right)^{1.81} \qquad (6)$$

where T_{STP} is standard temperature in K, T is ambient air temperature in K (average diurnal temperature for sampling period), D is diffusivity of NO_2 in ambient air in cm^2s^{-1} and D_{STP} is diffusivity of NO_2 in air at STP = 0.1361 cm^2s^{-1}.

3.6.4 Calculation of Sampling Rate of Samplers

From Fick's Law, the total mass uptake ΔM (g) of the tube sampler can be found by multiplying the mass flow per unit area with the cross section area of the bottom of the tube A (cm2) and the exposure time Δt (s). Theoretically the total uptake of a sampler ΔM (g) depends on the ambient concentration of pollutant Co (g/cm3) and the exposure time Δt (s).

$$\Delta M = S \times C_o \times \Delta t \qquad (7)$$

The coefficient of proportionality is called the sampling rate S (cm^3/s). It is a measure for the speed of the sampler type and should depend only on the geometry of the sampler. The sampling rate of the passive sampler can be read off from the following expression

$$S = \frac{DA}{l} \qquad (8)$$

where l is length of sampler in cm.

3.6.5 Calculation of Ambient Concentration in µg/ml

The ambient air concentration of NO_2 in µg/ml is calculated thus:

$$C_o = \frac{\Delta M}{S \Delta t} \qquad (9)$$

4. RESULTS AND DISCUSSION

Figure 3 shows the calibration plot for standard nitrite solutions. Statistical analysis showed that the fit gave a good measure of regression with r-square value of 0.9976. The validity of the plot was verified with the closeness of this value to unity. This observation is in consonance with past reports on calibration plot (Targa and Loader, 2008; Parra and George, 2004). All the absorbance measurements obtained were within the range of the standard nitrite solutions prepared. This calibration plot was therefore used in computing the concentration of nitrite in exposed passive samplers for the research.

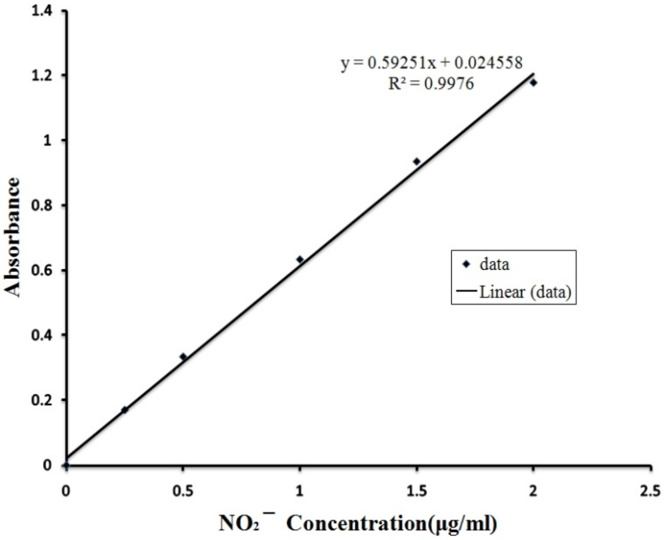

Figure 3: Calibration plot

Table 1 shows measured parameters for site 3. The mean temperature values observed during the sampling periods were computed from data supplied by Nigerian Mesoscale Experiment (NIMEX), Department of Physics, Obafemi Awolowo University, Ile-Ife. The absorbance readings of nitrite collected on exposed paper filters recovered from the samplers were measured with the UV/VIS Spectrophotometer. Ambient NO_2 concentrations were then calculated using the computation algorithm given above.

Table 1: Parameters for site 3

Type	Duration (weeks)	Temperature (^{0}C)	Absorbance	NO_2 Concentration	
				(µg/m^3)	(ppb)
1	2	26.7	0.1800	5.75	3.06
1	4	26.9	0.3335	5.61	2.98
2	2	26.7	0.0040	0.45	0.24
2	4	26.9	0.1305	7.69	4.09

The maximum observed NO_2 concentration in site 3, 4.1ppb, was obtained from sampler type 2 exposed for a sampling interval of 4 weeks. The minimum NO_2 concentration measured in this site was 0.2ppb from sampler type 2 with sampling duration of 2weeks. This considerably low value of 0.2ppb was due to leakages observed in the blank sampler which was not properly sealed. This exposed the absorbing filter paper to the ambient air, thereby causing the blank to absorb NO_2 in the air. Figure 4 shows the NO_2 concentrations measured with different sampler types deployed in site 3 and corresponding sampling durations. Statistical analysis showed that Pearson correlation coefficient is negative (r = -1), which is an indication of the error observed in sampling. There is therefore a significant difference between the ambient concentration of NO_2 measured by sampler type 1 and sampler type 2 deployed for 2 weeks. Despite this disparity, there is a considerable agreement between the ambient concentrations of NO_2 measured with the two sampler types, though the sampler type 2 gave the higher estimate.

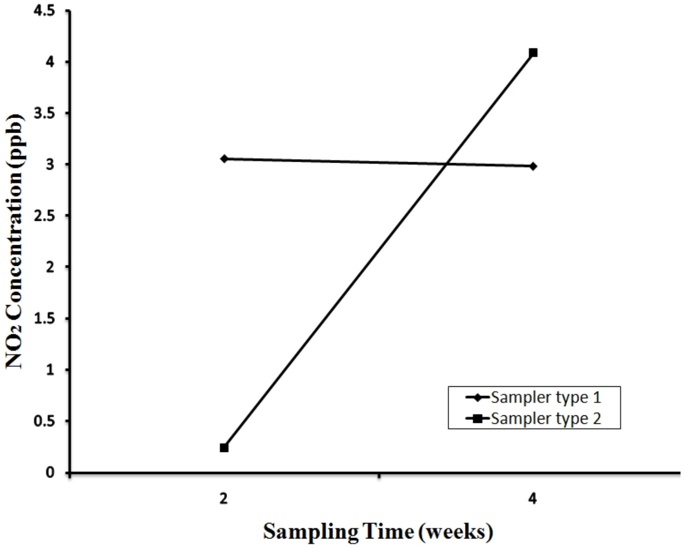

Figure 4: Plot for comparison of samplers in site 3

Measured parameters for site 2 are shown in Table 2. Using the data supplied by NIMEX, the sampling rates of the samplers were calculated. The modified Griess-Saltzman method was then employed in determining the absorbance readings of nitrite deposited on the paper filters. Corresponding values of NO_2 concentration were computed.

Table 2: Parameters for site 2

Type	Duration (weeks)	Temperature (^{0}C)	Absorbance	NO_2 Concentration	
				(µg/m^3)	(ppb)
1	1	27.2	0.2835	19.04	10.12
1	2	26.5	0.3325	11.21	5.96
1	3	27.2	0.3820	8.56	4.55
1	4	27.4	0.6040	10.14	5.39
2	1	27.2	0.0845	19.87	10.56
2	2	26.5	0.0950	11.21	5.96
2	3	27.2	0.1015	7.96	4.23
2	4	27.4	0.1695	9.96	5.29

Figure 5 shows the NO_2 concentrations measured with different sampler types deployed in site 2 and corresponding sampling durations. The NO_2 concentrations observed in site 2 ranged from 4.2ppb to 10.6ppb. The maximum value was obtained from measurement taken with sampler type 2 exposed for 1 week. The minimum value was given by the same sampler type but with a sampling duration of 3 weeks. Results showed that NO_2 concentration decreased as the sampling period increased. Pearson correlation coefficient, r = 0.9997, for the two sampler types also indicates that no significant difference was noticed in the ambient concentration measurements.

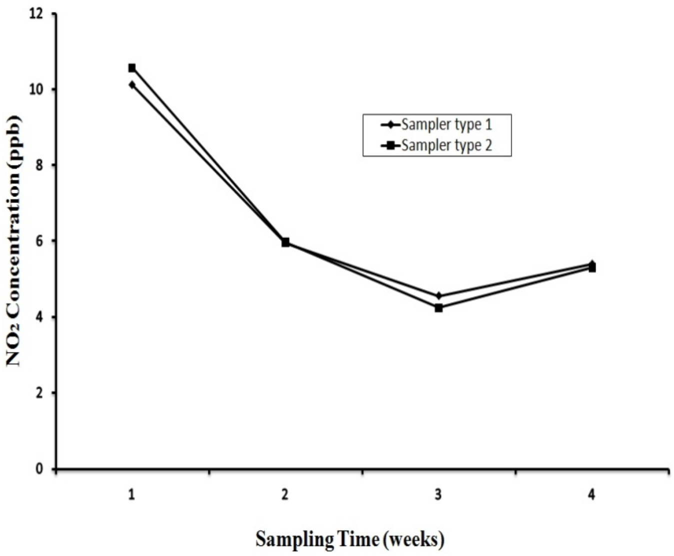

Figure 5: Plot for comparison of samplers in site 2

NO_2 concentrations measured with different sampler types deployed in site 1 and corresponding sampling durations are presented in Figure 6 while Table 3 shows computed parameter at the same site. Data for computation of mean temperature values during sampling period were collected from NIMEX. Samplers taken from the site were subjected to analysis and absorbance of nitrites collected was measured. The computation algorithm developed was carefully applied for determination of the ambient NO_2 concentrations in this site.

Table 3: Parameters for site 1

Type	Duration (weeks)	Temperature (^{0}C)	Absorbance	NO_2 Concentration	
				(µg/m^3)	(ppb)
1	1	27.2	0.2965	19.88	10.57
1	2	26.5	0.4880	16.47	8.75
1	3	27.2	0.5905	13.23	7.03
1	4	27.4	0.8985	15.08	8.02
2	1	27.2	0.0990	23.24	12.35
2	2	26.5	0.1690	19.96	10.61
2	3	27.2	0.2485	19.49	10.36
2	4	27.4	0.2570	15.10	8.03

The lowest measured value at this site was 7.0ppb and it was measured with the sampler type 1 of 3 weeks sampling duration. 12.4ppb was the maximum NO_2 concentration observed in this site and also the entire study. This relatively high value was measured with the sampler type 2 for a sampling duration of 1 week. The result was subjected to statistical analysis and it gave a value of r = 0.6681 which shows not so high, but considerable correlation of the two sampler types. A decrease in the ambient NO_2 concentration measurements was also observed with increase in sampling period.

Figure 7 shows the correlation of NO_2 concentrations obtained in site 1 and those of site 2 with sampler type 1. It was observed that values obtained in site 1 are higher than those in site 2. Statistical analysis also gave r-value of 0.9674. The results of one week sampling duration from both sites are close.

Figure 8 shows the correlation of NO2 concentrations obtained in site 1 and those of site 2 with sampler type 1. Values obtained from site 1 are also higher than those of site 2. Pearson correlation coefficient of 0.7237 was computed.

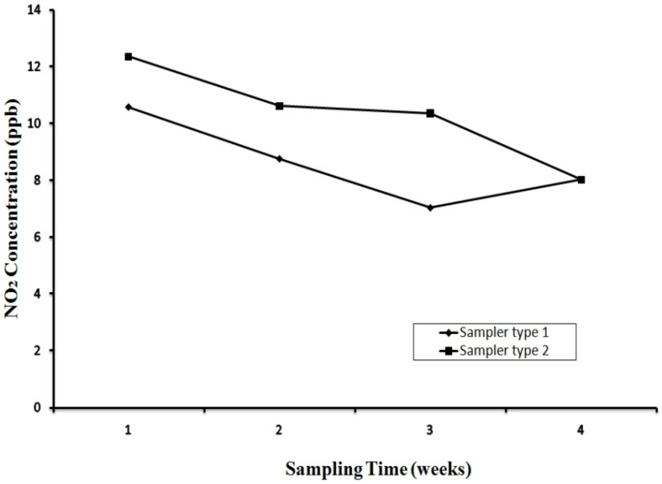

Figure 6: Plot for comparison of samplers in site 1

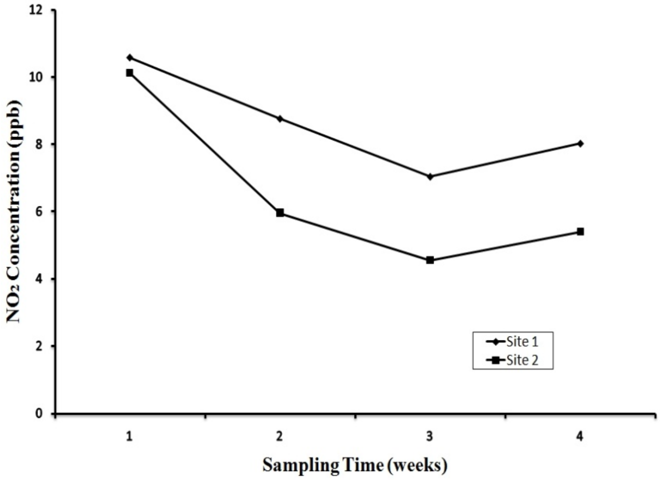

Figure 7: Plot for comparison of sampler type 1 in site 1 and site 2

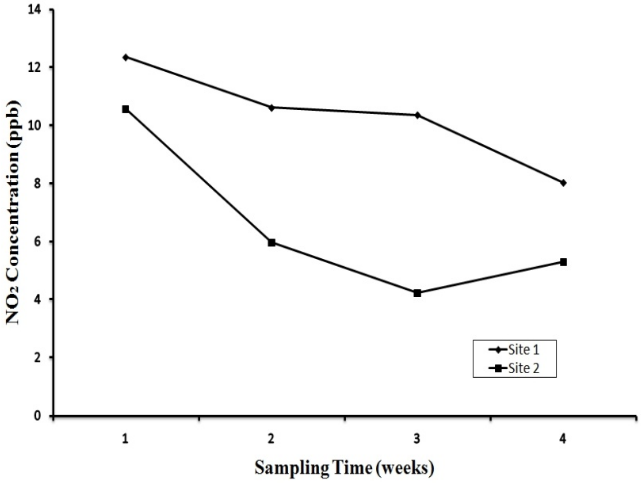

Figure 8: Plot for comparison of sampler type 2 in site 1 and site 2

The concentrations reported decreased as measurement duration increased. The literature represents such relationships by

$$C_2 = C_1 \left(\frac{t_1}{t_2}\right)^q \qquad (10)$$

where q = 0.17 to 0.2 (Nonhebel, 1960) and q = 0.5 (Hino, 1968).

Comparing concentrations obtained over a week sampling (C_1) with those for longer durations (C_2) would suggest q = 0.20 to 0.37 for sample site 1. This falls within the ranges of exponent q reported above. The exponents for the two other sites showed more scatter.

A direct-reading personal toxic gas monitor (Toxic RAE model) was also used in sampling for NO_2 at the three locations (albeit after the actual deployment dates of the passive samplers). This was done for verification of concentrations measured with passive samplers. This gas monitor was not sensitive enough to detect the level of NO_2 in the ambient air because it was calibrated to measure to one decimal place in ppm.

5. CONCLUSIONS

Results obtained from this study have shown that passive sampling methods of measuring air pollution can be used successfully in evaluating the ambient concentration of NO_2. The ambient concentration of NO_2 in OAU has been measured with passive samplers and herein reported. The highest measured ambient air concentration of NO_2 in OAU was 12.4ppb which is below the air quality standard for NO_2 as published by the Federal Ministry of Environment put between 40ppb – 60ppb. The major source of error was observed in allowing for leakages in the blank sampler deployed on field. Blanks are therefore supposed to be sealed and made air tight. One week sampling duration gave the highest estimates and there was loss in concentration of nitrite trapped in filter paper with time. Passive samplers are able to detect low levels of pollutants in the air. Correlation analysis also reveals that both sampler types can be used effectively. With reference to NO_2 standard earlier stated, there is no considerable threat to human beings and the ecosystem yet, but measures must be taken to keep the air clean.

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REFERENCES

Atkins, D. H. F. and Lee, D. S., "Spatial and temporal variation of rural nitrogen dioxide concentrations across the United Kingdom". Atmospheric Environment 29:223–239, 1995.

Atkins, D.H.F., Sandalls, J., Law, D.V., Hough, A.M. and Stevenson, K., "The measurement of nitrogen dioxide in the outdoor environment using passive diffusion tube samplers". AERE-R12133, United Kingdom Atomic Energy Authority, Harwell, 1986.

Campbell, G. W., Stedman, J. R. and Stevenson, K., "A survey of nitrogen dioxide concentrations in the United Kingdom using diffusion tubes, July–December 1991". Atmospheric Environment 28:477–486, 1994.

Coulson, J. M., Richardson, J. F., Backhurst, J. R., and Harker, J. H., "Chemical Engineering, Volume 1", Sixth Edition, Butterworth-Heineman, Elsevier, Oxford, 2004.

Dimari, G.A., Abdulrahman, F.I., Akan, J.C. and Ogugbuaja, V.O., "Levels of Nitrogen Dioxide of Atmospheric Air, in Maiduguri, Borno State, Nigeria". Research Journal of Applied Sciences 2(7): 846-849, 2007.

EPA, Environmental Protection Agency/Air Trends/Nitrogen Dioxide, September 21, 2004, http://www.epa.gov/airtrends/nitrogen.html, accessed on November 2, 2009.

EPA, Environmental Protection Agency/Office of mobile sources, January 17, 1997, http://www.epa.gov/otaq/consumer/05-autos.pdf, accessed on November 2, 2009.

Hangartner, M. and Burri, P., "Passive sampling of nitrogen dioxide and sulphur dioxide in ambient air". Communique of European Communities, [Rep.], (EUR 10555, Diffusive Sampling), 387-391, 1987.

Hewitt, C. N., "Spatial variations in nitrogen dioxide concentrations in an urban area". Atmospheric Environment 25:429–434, 1991.

Hino, M, "Maximum ground-level concentration and sampling time". Atmos. Environ. 2:149-165, 1968.

Hopke, P. and Markowitz, D., "A survey of monitoring instruments for measurement of airborne pollutants". CEC Consultant report no. 500-03-053F, New York State Energy Research and Development Authority (NY SERDA) Potsdam, New York, 2002.

IDAF, Measurements/Gas, March 3, 2004, http://idaf.mediasfrance.org/measurement/gas/index, accessed on January 27, 2009.

Kirby, C., Fox, M. and Waterhouse, J., "Reliability of nitrogen dioxide passive diffusion tubes for ambient measurement: in situ properties of the triethanolamine absorbent". Journal of Environmental Monitoring 2:307- 312, 2000.

Kirby, C., Greig, A. and Drye, T., "Temporal and spatial variations in nitrogen dioxide concentrations across an urban landscape: Cambridge, U.K". Environmental Monitoring and Assessment 52:65–82, 1998.

Lodge J.P. (ed.), "Method 406: Determination of the Nitrogen Dioxide Content of the Atmosphere (Griess-Saltzman Reaction)". In Methods of Air Sampling and Analysis, 3rd ed. Intersociety Committee (APCA, ACS, AIChE, APWA, ASME, AOAC, HPS, ISA). Michigan, USA, Lewis Publishers Inc., 389-393, 1989.

Massman, W. J., "A review of the molecular diffusivities of H_2O, CO_2, CH_4, CO, O_3, SO_2, NH_3, N_2O, NO, and NO_2 in air, O_2 and N_2 near STP". Atmospheric Environment, 32(6):1111-1127, 1998.

Microsoft® Encarta® 2009 [DVD], "Air Quality". Redmond, WA: Microsoft Corporation, 2008.

Nonhebel, G., "Recommendations on heights for new industrial chimneys". J. Inst. Fuel 33:479-511, 1960.

Palmes, E.D., Gunnison, A.F., DiMattio, J. and Tomczyk, C., "Personal sampler for nitrogen dioxide". American Industrial Hygiene Association 37: 570-577, 1976.

Parra, J. and George, L., "Performance and Application of an Inexpensive method for Measurement of Nitrogen Dioxide", Portland State University, 2004. (Unpublished).

Plaisance, H., Piechocki-Minguy, A., Garcia-Fouque, S. and Galloo, J. C., "Influence of Meteorological factors on the NO$_2$ measurements by passive diffusion tube". Atmospheric Environment 38:573-580, 2002.

Shooter, D., Brimblecombe, P., Shooter, J., Lowe, D., Day, P. J. and Du, S., "Some characteristics of nitrogen dioxide passive samplers". Environmental Technology 18:243-254, 1997.

Sonibare, J. A. and Jimoda, L. A., "Criteria air pollutants from some anthropogenic combustion processes in Lagos, Nigeria". Energy Sources, Part A: Recovery, Utilization and Environmental Effects 31(11):923-935, 2009.

Targa, J. and Loader, A. Diffusion tubes for ambient NO$_2$ monitoring: Practical guidance. Report to Defra and the Devolved Administrations, ED48673043, AEA/ENV/R/2504-Issue 1a, February 2008.

Targa, J., Rendell, A. and Truesdale, V., "Investigation on pH, TEA and colour reagent dependency during nitrite analysis". Report in preparation to Defra & the Devolved Administrations by AEA Energy & Environment, 2007.

Van Reeuwijk, H., Fischer, P. H., Harssema, H., Briggs, D. J., Smallbone, K. and Lebret, E., "Field comparison of two NO$_2$ passive samplers to assess spatial variation". Environmental Monitoring and Assessment 50:37–51, 1998.

Vrana, B., Mills, G., Allan, I., Dominiak, E., Svensson, K., Knutsson, J., Morrison, G. and Greenwood, R., "Passive sampling techniques for monitoring pollutants in water". Trends in Analytical Chemistry 24:845-868, 2005.