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THE EFFECT OF INDUSTRIAL AIR – BORNE POLLUTANTS ON THE DURABILITY OF GALVANIZED IRON ROOFS IN THE TROPICAL HUMID REGION OF NIGERIA

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ABSTRACT

This paper examines the influence of atmospheric pollutants on one widely used building material, the galvanized iron roofing sheets, in the highly polluted region of Niger Delta of Nigeria. The study involved the atmospheric exposure of cut pieces of galvanized iron sheets to determine the influence of sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate matter (all by-products of gas flaring) in a humid tropical environment. The pollutants were in the mean concentrations of 0.09 – 0.68mg/l (SO_2), 0.01- 0.35mg/l (NO_2) and 7.22 – 20.65µg/m^3 (aerosol). The readings of concentration of the pollutants were recorded and multiple regression analysis was performed on the data. After one year of exposure of the specimens, it was discovered that corrosion was enhanced by the presence of these pollutants. Examination of the partial coefficients of the pollutant revealed that, nitrogen dioxide (r = 0.460) and particulate matter (aerosols) (r = 0.569) were found to correlate positively with corrosion in a multi-pollutant situation. However, it was found that sulphur dioxide (r =-0.213) did not positively contribute to corrosion impact, contrary to established results from temperate regions. It is recommended that the Nigerian Government should legislate to stop gas flaring in the region.

KEY WORDS: Galvanized iron, gas flaring, Niger Delta, nitrogen dioxide, sulphur dioxide.

INTRODUCTION

Atmospheric pollution is one of the major global issues because of its wide spread impacts, ranging from health to material degradation. However, the single impact that has attracted the attention of architects, engineers and builders more than any other is the corrosion of metallic components (Graedel, 1986; Chotinmongkol *et al*, 1999 & Obia, 2008). Metal is a key material in the construction industry, including other engineering fields. Over the years, corrosion scientists and engineers have occupied themselves with finding ways of preventing corrosion because of the yearly cost associated with this plague (Obia, 2008).

The situation has not been different in the Niger Delta region of Nigeria where this study was conducted. Petroleum exploitation in this region is associated with the release of entrapped natural gas that more than 50% of which is often flared. The flaring process is known not to meet international environmental standards (Egbuna, 1987). Since the active exploitation of crude oil began in the region some four decades ago, there has been a noticeable reduction in the lifespan of the galvanized iron roofing sheets (World Bank, 1995). The reduction in the lifespan of the roofing sheets has led to widespread protests by the people, directed at oil companies (Obia, 2008). The principal players in the upstream oil sector, the multi-national oil firms, have often vehemently denied complicity in the degradation of this roofing material (Inyang, 2001). Their arguments were anchored on the often-held view that Nigerian crude is low in sulphur and therefore would not promote atmospheric corrosion (World Bank, 1995). The companies suggested that sea salts (aerosols) could be responsible for the rapid wear of the material. That argument has been countered by the local residents, who make historical reference to the longevity of this same material in the region in the pre-oil era, dating back to the colonial days.

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The uncertainty of the causes of metallic corrosion in the region has necessitated scientific inquiry. Hitherto and unfortunately, no single detailed region-wide study of atmospheric corrosion had been done since the beginning of oil era. This study was one in a series of tests conducted in the region with the main objective of discovering the actual causes of the failings of the roofing materials, particularly whether the corrosion of galvanized iron was due to pollutants exuded as by-products of petroleum production processes such as gas flaring. The study was also aimed at identifying the type of pollutants involved and their relative influences, besides synergy, if any, existing among these pollutants in the corrosion menace.

MATERIALS AND METHOD

Small sizes of commercial corrugated galvanized iron roofing sheets of "SWAN" brand, locally called "zinc", were cut to a uniform size of 100mm x150mm each. The small sizes were made for easy manipulation and higher accuracy of measurement (Obia, 2008). A large number of small size specimens have the advantage that the several replicates would give a more reliable measure of corrosion than a single large sheet. Moreso, specimen size has been known to critically relate to the volume of corrodants produced (Ailor, 1982).

The specimens were weighed with a sensitive electronic weighing balance (WA210 model) with sensitivity of 0mg – 21.0g, manufactured by Adams Equipment, United Kingdom.. It is the preferred equipment for the determination of mass loss in atmospheric corrosion tests where the exposure duration is short and mass loss values relatively small. The pollutants were sampled with automatic environmental monitoring station manufactured by ELE International, United Kingdom. The station is equipped with nitrogen dioxide and sulphur dioxide sensors with a range of 0 - 100ppm with accuracy of ± 1ppm.

Particulate matter concentrations (aerosols) were sampled with a high airborne particulate monitor (AMS950IS model) manufactured by CASELLA Limited, Bedford, United Kingdom with a range of 0.1 – 199.9μg/m^3. The pollutants sampling was done for one hour between the hours of 0700 and 1800 once every two weeks around each station. The galvanized iron specimens were washed with ethanol and rinsed in clean water, and dried. This cleaning exercise was conducted before and after every exposure event. Other equipment included a wooden frame and plastic strings.

There were three approaches to verifying the performance of metallic components and these include outdoor exposure, chamber tests and analytical tests (Cole et al, 1999). This study was an outdoor exposure programme carried out on three sites. This paper therefore examines the outcome of these tests. The three study sites were selected based on their peculiar environmental conditions as well as determined basic criteria that would enhance uninterrupted pollutant sampling. The criteria included accessibility and suitability of open space, wind regime as well as absence of extraneous pollutant sources like motor vehicles and bush burning. The sites were National Agip Oil Company (NAOC) flow station at Ebocha village in Rivers State, designated as "A" in this study and Mobile Oil Producing Unlimited Terminal (QIT) at Ibeno, Akwa Ibom State, designated as "B". The third site, "C", was at Abamba village in Cross River State. The description of the sites is as shown in Table 1. The first two stations were areas of concentration of gas flare stacks and of the same average climatic conditions. The last station was the experiment control station with no flare activities and no vehicular exhaust influence. Abamba, the control station, is located in the tropical rain forest of Cross River State, more than 150km away from oil producing stations and not less than 20km from the busy Ikom - Calabar motor highway.

The average temperature, relative humidity and precipitation of the region were 27^{o}C, 85% and 4000mm respectively (World Bank, 1995). The wind speed was relatively mild. Though different companies operate the different flow stations, there was a common characteristic noticeable among the flares from the stacks. The flares were orange and sooty in appearance, suggesting that the combustion had been incomplete (Egbuna, 1987).

The experiment involved the suspension of four replicate samples of the metal on wooden frame inclined at 30^o and stationed at distances of 100m, 200m, 300m and 400m away from, and facing each of the flow stations or assumed position in a southwest – northeast direction. The specimens were strung taut on the wooden frame with the aid of the plastic strings to avoid contact with any corrosive object. The rack was fixed to a wooden post at a height of 1.2m from the ground surface. This height ensured that rain splashes from the surrounding ground did not influence the outcome of the experiment.

In situ monthly concentrations of the gases and aerosols were recorded in the immediate environment of each rack station. The specimens were removed at the end of the experiment and washed, dried and re-weighed to determine the mass loss at each of the twelve stations of the study. The mean and standard deviation of each of the parameters were taken across the three sites and computed using SPSS computer software. Multiple regression analysis was subsequently carried out on the data because of the multi-pollutant and dynamic nature of the atmosphere.

RESULTS

Table 2 shows the mean mass losses and standard deviations of all the dependent and independent variables within each site and across the sites. The analysis produced the following regression coefficients; -10.918 (constant), -10.919 for variable x_1, 64.261 for variable x_2 and 1.102 for variable x_3. The emergent regression model is

$\mathbf{Y = -10.918 – 10.919x_1 + 64.26x_2 + 1.10x_3}$ or

$\mathbf{Y = 1.10x_3 + 64.26x_2 – 10.92x_1 – 10.918}$, where,

Y = Mass loss, the dependent variable

$\mathbf{x_1}$ = sulphur dioxide (SO_2)

$\mathbf{x_2}$ = nitrogen dioxide (NO_2) independent variables

$\mathbf{x_3}$ = aerosol concentration

Other vital computed statistics are as follow: R^2 is 0.71, significant value of 0.015 and an F value of 6.529 within the degrees of freedom of 3 and 8.

Table 1: Site classification

location	environment	latitude	unique characteristics
"A" NAOC , Ebocha	flare only	05^o28^1N/ 06^o41^1E	Rural village with gas flare points
"B" QIT, Ibeno	marine/flare	04^o32^1N/ 07^o55^1E	oil flow station with flare points and situated by the sea side
"C" Abamba	non-marine/ non-flare	05^o46^1N 07^o59^1E	open school compound in a forested village

Table 2: Mean readings of mass losses and pollutant concentrations, January to December, 2005.

Site	Station	Distance from flare point or assumed position (m)	Mean mass loss(mg)	Mean SO_2 conc.(mg/l)	Mean NO_2 conc.(mg/l)	Mean aerosol conc.(µg/m^3)
"A" NAOC, Ebocha	S_1	100	15.65	0.15	0.18	16.70
	S_2	200	21.50	0.09	0.17	15.45
	S_3	300	11.55	0.55	0.25	8.75
	S_4	400	0.20	0.10	0.01	9.87
Mean			12.23	0.23	0.15	12.69
Std. dev.			9.0	0.22	0.10	3.97

"B" QIT, Ibeno	S_5	100	20.65	0.68	0.35	17.80
	S_6	200	25.90	0.51	0.20	16.08
	S_7	300	20.60	0.61	0.32	20.65
	S_8	400	21.25	0.31	0.16	18.77
Mean			22.10	0.53	0.26	18.33
Std. dev.			2.55	0.16	0.09	1.91
"C" Abamba Village	S_9	100	2.75	0.16	0.10	15.37
	S_{10}	200	0.90	0.30	0.09	12.30
	S_{11}	300	0.30	0.48	0.16	8.32
	S_{12}	400	1.30	0.25	0.11	7.22
Mean			1.31	0.30	0.12	10.80
Std. dev.			1.04	0.14	0.03	3.75
Grand mean			**11.89**	**0.35**	**0.18**	**13.94**
Grand std. deviation			**10.14**	**0.21**	**0.10**	**4.50**

DISCUSSION

The mean mass loss of 22.10 ± 2.55mg at QIT, Ibeno is the highest across the three sites, compared to Ebocha with a mean mass loss of 12.32 ± 9.0gm. This indicates that QIT is certainly the most impacted of all the sites. The relatively small standard deviation at QIT suggests that there is less variation in mass loss between the experiment stations within the site. Abamba was the least impacted site with a mean mass loss of 1.31 ± 1.14mg. The grand mean mass loss (the mean of the mass loss across the sites) is 11.89 ± 10.14 (lower than the figure at QIT). Ebocha site with a mean mass loss of 12.90 ± 9.10mg is next in the degree of corrosion impact; however, the relatively higher standard deviation of 9.10 suggests a great variation in mass loss among the stations at the site.

Thus, pollutant concentrations influenced corrosion significantly. A high coefficient of determination (R^2 = 0.71) shows that about 71% of the impact is attributable to atmospheric pollutants. The individual influences of the pollutants could be analyzed from the computed data. Individual correlation (partial) show that aerosol has the highest positive influence with correlation coefficient of 0.569, followed by nitrogen dioxide with 0.460. Sulphur dioxide with a partial correlation of -0.213 is next to nitrogen dioxide; however, its influence is negative. In a multi - pollutant situation, the partial and part correlation indices of the pollutants suggests that sulphur dioxide contributed negatively to the impact, with corresponding figures of -0.213 and -0.117, whereas aerosol and nitrogen dioxide had positive influences with corresponding partial and part coefficients of 0.560 and 0.373, and 0.460 and 0.279 respectively.

It is reported that nitric acid is known to be highly reactive and does not even need high humidity to attack materials (Tidblad *et al*., 1996; Johnson & linder, 1993). Equally, nitrogen dioxide reacts with carbonaceous particles (soot) found as component of particulate matter (aerosol) to yield nitric acid and oxygen. The atmosphere of this region is laden with soot and other hydrocarbon particles because of incomplete combustion in the flare chambers (Egbuna, 1987).

The region's wet-humid climate creates a congenial atmosphere for corrosion effects. This study also reveals that sulphur dioxide, often accepted as a major industrial pollutant responsible for corrosion in temperate climates (Tidblad *et al*, 2000; Cole *et al.,1999* & Graedel *et al.,1989*) rather has negative influence in the promotion of atmospheric corrosion in the region,

while the greatest contributor to the rust of galvanized iron roof in the region is aerosol (fine particulate matter with a complex admixture of solid and gaseous compounds released from gas flare chambers and the sea). This paper has shown that atmospheric pollutants significantly influence the corrosion of galvanized iron roofs in the Niger Delta. The positive correlation of nitrogen dioxide and aerosol, both bi-products of combustion, suggests that gas flaring contributed to corrosion impact in the region. The attention of Government to the gas flaring in the region is necessary.

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