Assessment of Indoor Power Frequency Electric and Magnetic Fields In Industrial Environment: Pz Cussons Nigeria PLC, Ikorodu, Lagos, as A Case Study

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***Abstract*— In industries, heavy duty machines and equipment are being used to perform different functions, and there is need for cables of different capacities to supply power to the electric motors that drive these equipment. Electromagnetic fields are generated due to mains current flowing in the cables and are known as power frequency fields which are in the extremely low frequency (ELF) range. This paper presents the measurement carried out in PZ Cussons Nigeria PLC, Detergent Factory, Ikorodu, Lagos in Nigeria to ascertain the peak intensity of indoor power frequency electric and magnetic fields that personnel working in this environment are exposed to. Heavy duty electric machines are being used in this factory, therefore typical of a suitable case study. Measurements within the premises (Detergent Packing Hall and Tower Detergent Factory) using Tenmars TM-195 RF Test Meter was carried out, and level of exposure to these fields was assessed by comparison with the threshold specified by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) for safety. The results showed that the maximum peak values of the measured electric and magnetic fields are 6.714 V/m and 23.968 μT respectively, and they occurred at the same location in the Tower Detergent Factory which houses operational electric motors of highest rating within the factory. These values are 0.067% and 4.79% respectively of the Occupational threshold of 10 kV/m and 500 μT as specified by ICNIRP. For General Public threshold of 5 kV/m and 100 μT, the maximum peak values of the electric and the magnetic fields measured in the Parking Hall are 1.1987 V/m and 1.92 μT respectively, which are 0.024% and 1.92% respectively of the threshold for general public by ICNIRP. This ascertains that exposure of personnel working in this industrial environment to ELF electromagnetic fields are within safe limit, and by extension other similar industrial environments in the country.**

Keywords*— *magnetic field; electric field; mains current; extremely low frequency; exposure threshold

I. INTRODUCTION

Exposure to man-made electromagnetic fields (EMF) has been steadily increasing from the immediate past century to the current century, and this is due to increasing electricity demand and ever-advancing technologies all over the world [1]. There is exposure to electric and magnetic fields, both at home and at work, from the generation, transmission and distribution of electricity, to telecommunications and broadcasting [2].

Whenever electricity flows, electric fields are produced which is shielded by most common materials, such as wood and metal that exists close to the path of the electricity. Also magnetic field arises from the current, and is not shielded by most common materials. Electric and magnetic fields are present around all wires carrying electricity. The strength of the electric field depends on the voltage, while the strength of the magnetic field depends on the size of the current being carried. The strength of the fields reduces rapidly with distance from the wires [3, 4].

An alternating current oscillates backwards and forwards, and the magnetic and electric fields produced by such a current also oscillate at the same rate. Electromagnetic (EM) fields are generated either deliberately as in telecommunications or as part of industrial and other processes utilizing EM energy or emitting it unknowingly, e.g. through the use of electric motors and generators. People both at home and at work are exposed to electric and magnetic fields arising from a wide range of sources that use electrical energy. The electric and magnetic fields vary rapidly with time, and the rates at which they vary cover a wide spectrum of frequencies.

The magnetic and electric fields produced by an oscillatory current conventionally making 50 or 60 complete cycles every second falls into a range referred to as extremely low frequency (ELF) fields [5]. All electric appliances operate at a frequency of 50 Hz or 60 Hz, and close to these appliances, electric and magnetic fields exist. The increasing rate at which devices which emit these fields are flooding our environment, calls for the need to be aware of the fields' intensity for possible precautionary measure.

Many studies have linked electromagnetic field with various health hazards ranging from changes in cognitive performance and sleep disturbances to serious illness and disablement. Questions have been raised whether exposure to these extremely low frequency (ELF) electric and magnetic fields produces adverse health consequences. Much research has been done, successfully resolving important issues and narrowing the focus of future research [6].

Electromagnetic field exposures vary substantially between industries, different occupations and home. In factories and large commercial buildings, the occupants may be exposed to substantial amount, especially those in electric power stations. Seyhan et al., (2013) carried out EM field occupational exposure measurement study to characterize personal magnetic field exposure among operators using office equipment and/or industrial workstations. Based on their findings, it was strongly recommended that periodic EM field exposure measurements should be done to obtain more detailed understanding of workplace exposures and their sources [1]. Ibrahim et al., (2013) examined the magnetic field pollution from electric appliances and fixtures in residential area of Bauchi metropolis in Nigeria as a case study. The result showed that most of the appliances examined need to be kept at a distance of around 20cm from human body to avoid health risk [7].

The ever increasing knowledge of the biological effects of low frequency electromagnetic (EM) fields has led to research works on other health issues caused by over exposure to electromagnetic fields [8 – 19]. It is therefore important to frequently check the level of exposure of our environment to electromagnetic fields to be able to detect cases of EM field pollution on time.

The aim of this work is to ascertain, through measurements, the peak intensity of indoor power frequency electric and magnetic fields in a typical industrial environment, taking PZ Cussons Nigeria PLC, Ikorodu, Lagos, in Nigeria as a case study. The measurements are limited to the premises of the industry.

II. ELECTROMAGNETIC RADIATION AND STANDARDS FOR LIMITING EXPOSURE

A. *Electromagnetic Radiation*

Electromagnetic radiation is energy radiated by an accelerated charged particle. James Clark Maxwell derived a mathematical framework based upon Faraday's empirical data on magnetic lines of force. Electric and magnetic fields in the electromagnetic wave are oriented at right angle to each other, and together as a wave propagate out in all directions, creating a spherical wave front.

For a given source emitting radiofrequency (RF) energy at a power level P_{tx}, the power density S, in Wm^{-2} is given by:

$$S = \frac{P_{tx}}{4\pi d^2} \qquad (1)$$

where d is the distance between the radiator and the wave front (radius of the sphere). The frequency range of electromagnetic waves forms the electromagnetic spectrum.

B. *Specific (energy) Absorption Rate (SAR)*

Dosimetry is the term used to describe the process of determining internal quantities relating to exposure in tissues such as the electric field strength, induced current density and energy absorption rate, from external fields [20]. At frequencies below 100 kHz, the electrical quantity identifiable with most biological effects is the electric field strength in tissue, which is related to the current density. However, the more appropriate quantity at higher frequencies is the energy absorption rate, which is related to the square of the electric field strength in tissue. The rate at which energy is absorbed by a particular mass of tissue, m, is

$$EAR = \frac{m\sigma E^2}{\rho} \qquad (2)$$

where σ and ρ are the electrical conductivity and density of the tissue respectively, and the E is the rms value of the electric field strength. For a unit mass of tissue, the quantity is called the specific (energy) absorption rate (SAR) and is measured in watts per kilogram. It varies from point to point in the body because the electric field changes with position and the conductivity is different for different types of tissue.

C. *Magnetic Fields*

The magnetic fields generated by currents can be calculated from Ampere's Law or the Biot-Savart Law which is characterized by the magnetic flux density B measured in Tesla. It is a common practice to define another magnetic field quantity, usually called the "magnetic field strength" designated by H which can be defined by the relationship:

$$B = \mu H \qquad (3)$$

where μ is the permeability of the medium in which the field exists. For air, $\mu = \mu_o$ and is given to be 1.2566353×10^{-6} Hm^{-1}.

The occupations where exposure to fields has been investigated in greater detail tend to be those involving power workers. For instance, [21] reported that a typical worker in a UK power station experiences an average field of a few microteslas during working hours, and an electrician perhaps one microtesla. By contrast a typical office worker experiences about 0.2 microtesla. Fields in roads and public areas can be a microtesla above buried cables [21].

D. *Electromagnetic Fields Effect and Standards for Limiting Exposure*

In 1996, the World Health Organization (WHO) established the International Electromagnetic Fields Project to investigate potential health risks associated with technologies emitting EM fields [6]. Exposures to electromagnetic field radiation, according to Hamblin and Wood, (2002) can affect the natural rhythms of the brain's electrical activity [22]. Wolf and Wolf, (2004) opined that exposure to too high intensity of this field can result to higher cancer rates [23].

Electromagnetic field standards are established to limit overexposure to electromagnetic field levels that are present in the environment, and the guidelines ensure that no known adverse health effect will occur within the given exposure limit. Seyhan *et al*. (2013) reported that in order to protect the human populace from potential adverse effects associated with electromagnetic fields produced from the use of electricity and other sources, a number of national and international organisations have formulated guidelines establishing limits for occupational and residential exposure to electromagnetic fields. They mentioned that these organizations include the International Radiation Protection Association/International Non-Ionizing Radiation Committee (IRPA/INIRC), the Comité Européen de Normalization Electrotechnique (CENELEC), the National Radiological Protection Board in the United Kingdom (NRPB), Deutsches Institut für Normung-Verband Deutscher Elektrotechniker (DIN/VDE), the American Conference of Governmental Industrial Hygienists (ACGIH), and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [1]. Some others are World Health Organisation, the Institute of Electrical and Electronics Engineers (IEEE), International Committee on Electromagnetic Safety (ICES), and the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). These guidelines came about after series of certified research and findings [24 – 33].

The National Radiological Protection Board (NRPB) working in partnership with the Health Protection Agency recommends that restrictions on exposure to EM fields in the UK should be based on the guidelines issued by the ICNIRP [34].

The International Commission on Non-Ionising Radiation (ICNIRP) provides scientific advice and guidance on the health and environmental effects of non-ionising radiation (NIR) to protect people and the environment from detrimental NIR exposure. They give recommendations on limiting exposure to EM field; publish guidelines, statements and reviews used by regional, national and international radiation protection bodies [35]. Basic restrictions and reference levels for occupational and public exposures to 50 Hz extremely low frequency (ELF), electric and magnetic fields which was given by ICNIRP is shown in Table 1 [26].

Table 1: Reference Levels for Occupational and Public Exposures to 50 Hz Electric and Magnetic Fields [26]

Exposure Characteristics	Electric Field Strength (kV/m)	Magnetic Flux Density (μT)
Occupational	10	500
General Public	5	100

III. MATERIALS AND METHODS

A. *Study Location and Description*

The corporate headquarters of PZ Cussons PLC for Nigeria is in Ilupeju, Lagos State. The production lines for some of their personal care brands, home care, the food and nutrition brands (PZ Wilmar and Nutricima) as well as their largest distribution centre are located in the PZ Ikorodu Factory [36]. PZ Cussons Nigeria PLC Ikorodu Factory is located at 835 Ikorodu - Sagamu Road, Ikorodu, Lagos State, in Nigeria. It has coordinates 6.675961^{o} N, 3.515613^{o} E. It houses five different factories: Tower Detergent, Personal Care 1, Personal Care 2, Nutricima and PZ Wilmar. This work was carried out at Tower Detergent factory and Detergent Packing Hall since the highest number of electric motors of higher ratings; 195 kW and 200 kW are located there.

In the packing hall, there are twenty-eight Packona machines of double heads that packed the produced detergent into sachet of different grammes. The average number of staff that is always available in the packing hall is thirty-six (36). The Detergent Tower is a factory that produces detergent of twenty tonnes per hour for branded products and twelve tonnes per hour of buck detergent powder using spraying drying method. The Detergent Tower has six floors. A map of Lagos State in which the industry is located is shown in Fig. 1. The layout of the factory is sketched in Fig. 2, and its description is shown in Table 2.

Fig. 1: Map of Lagos State [37].

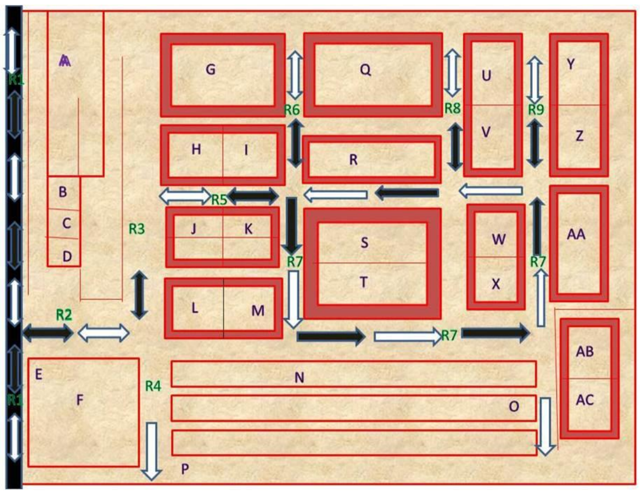

Fig. 2: The Layout of the Factory.

Table 2: Description of the Layout in Fig. 2

S/N	Abbrev.	Meaning	S/N	Abbrev.	Meaning
1	R1	Shagamu Road	20	S &T	Personal Care and Morning Fresh
	R2-R9	Factory Road			
2	A	Training School	21	U	Silicate Plant
3	B	Switch Room	22	V	Sulphurnation Plant
4	C	Switch Room	23	W	Engineering Store
5	D	Switch Yard	24	X	Material Store
6	E	Reception	25	Y	Personal Care 2
7	F	Car Park	26	Z	Personal Care Extension
8	G	Raw Materials Store	27	AA	Distribution Center
9	H	Raw Materials Store	28	AB	Effluent Treatment Plant
10	I	Pneumatic/Old Slurry	29	AC	Old Household Detergent Plant
11	J	Tower	30	PH	Packing Hall
	J1	Admin			
12	K	Detergent Packing	31	GF	Tower Ground Floor
	K1	Canteen/Finished Good Packing			
13	L	Power	32	TFF	Tower First Floor
14	M	Packaging Store	33	TSF	Tower Second Floor
15	N	Water Way	34	MCCR	Machine Control Center Room
16	O	ATM 2	35	TF	Tower Third Floor
17	P	ATM 1	36	FOF	Tower Fourth Floor
18	Q	Machine Workshop and Utilities	37	FIF	Tower Fifth Floor
19	R	Clinic and Tank Farm	38	SF	Tower Sixth Floor

B. *Materials and Measurement Method*

The measurement was carried out in the Packing Hall, the Machine Control Center (MCC) Room and the Tower's Ground Floor to the Sixth Floor. The measurement was made possible with the use of the battery-operated Tenmars TM-195 RF Test Meter. It has a frequency range of 50Hz to 3.5GHz with automatic range selector. In the Packing Hall, measurement was made at nine locations designated as PH1 – PH9. In the Tower Detergent factory, measurements were made at three locations in the ground floor (designated as GF1, GF2, and GF3); three locations in the tower first floor (designated as TFF1, TFF2, and TFF3); four locations in the tower second floor (designated as TSF1, TSF2, TSF3, and TSF4); two locations in the third floor (designated as TF1, and TF2); two locations in the fourth floor (designated as FOF1, and FOF2); two locations in the fifth floor (designated as FIF1, and FIF2); three locations in the sixth floor (designated as SF1, SF2, and SF3); and one location in the MCC room.

While taken the measurements great care was taken to avoid body contact with the instrument since the skin can absorb, reflect or even amplify the fields, thereby affecting the measurement accuracy of the test meter. Another precaution taken is that the meter was held still for a few seconds before reading the value from the display (moving the meter, static electric charges and the earth's field could sometimes be detected and give a false reading).

The magnetic field strength, H can only be measured by the instrument in Am^{-1}, hence the need to convert its readings to magnetic flux density, B, by using (3). By considering air as the medium, the magnetic flux density in tesla was calculated.

IV. RESULTS AND DISCUSSION

A. *Packing Hall*

Fig. 3 and Fig. 4 show the measured electric field strength E, and the evaluated magnetic flux density B, in the Packing Hall respectively. The magnetic flux density B was evaluated from the measured magnetic field strength H as mentioned in the previous section.

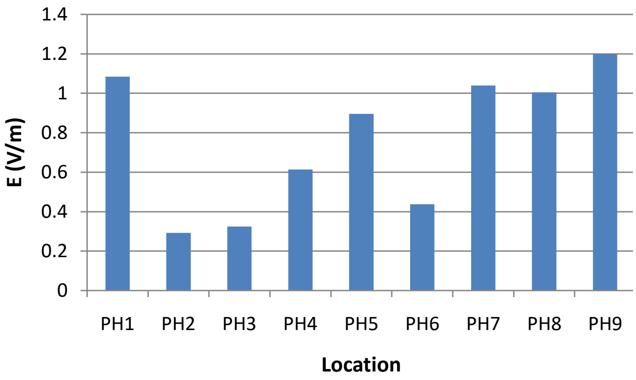

Fig. 3: Measured electric field strength in the Packing Hall.

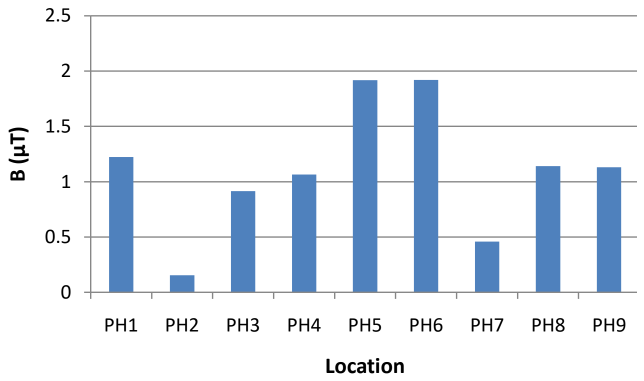

Fig. 4: Evaluated magnetic flux density from the measured magnetic field strength in the Packing Hall.

From the figures, the highest value of the electric field strength E, measured is 1.1987 V/m, and this occurred at PH9. The highest magnetic flux density B, evaluated from measurement is 1.92 µT and was obtained at PH6. These are 0.024% and 1.92% respectively of the threshold for general public by ICNIRP which are 5 kV/m and 100 µT. Therefore, exposure of workers working in this hall is well below the safety limit.

B. *Tower Detergent Factory*

Fig. 5 and Fig. 6 show the measured electric field strength E, and the evaluated magnetic flux density B, in the Tower Detergent Factory. The magnetic flux density B was evaluated from the measured magnetic field strength H.

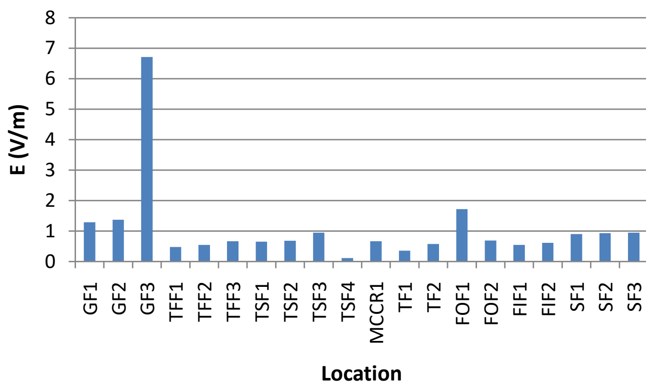

Fig. 5: Measured electric field strength in the Tower Detergent Factory.

From figures 5 and 6, the highest value of the electric field strength E, measured is 6.714 V/m, and this occurred at the Tower's ground floor which houses operational electric motors of highest ratings within the factory. The highest magnetic flux density B, evaluated from measurement is 23.9680 µT and was obtained at the ground floor as well, in fact at the same location for the electric field designated as GF3. These are 0.067% and 4.79% respectively of the threshold for Occupational exposure by ICNIRP which are 10 kV/m and 500 µT. Therefore, exposure of workers working in this factory is well below the safety limit.

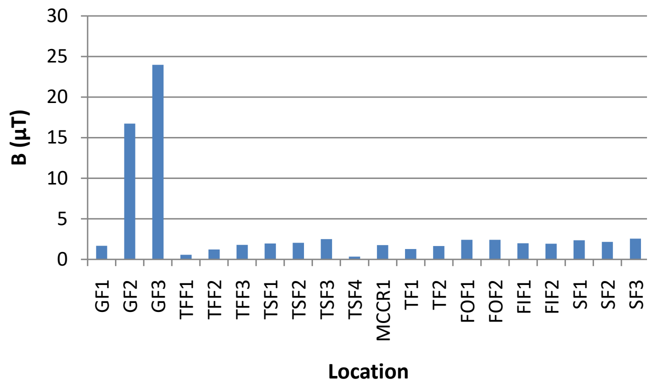

Fig. 6: Evaluated magnetic flux density from the measured magnetic field strength in the Tower Detergent Factory.

C. *General Discussion*

From the aforementioned results, the maximum, the minimum and the mean values of the fields with standard deviation from the mean are listed in Tables 3 and 4. The higher values occur within the Tower Detergent factory, while the lower values are in the Packing Hall.

Table 3: Minimum and maximum values of the electric field strength measured within the buildings

Building	Floor	Electric Field Strength (V/m)			
		Min.	Max.	Mean	S. D.
Packing Hall		0.2924	1.1987	0.7657	0.3515
Tower Detergent Factory	Ground Floor	1.2868	6.7140	3.1237	3.1095
	First Floor	0.4737	0.6687	0.5635	0.0984
	Second Floor	0.1169	0.9437	0.5972	0.3465
	Third Floor	0.3573	0.5745	0.4659	0.1536
	Fourth Floor	0.6884	1.7178	1.2031	0.7279
	Fifth Floor	0.5440	0.6136	0.5788	0.0492
	Sixth Floor	0.9014	0.9449	0.9262	0.0224
	MCC Room			0.6629	

Table 4: Minimum and maximum values of the magnetic flux density within the buildings

Building	Floor	Magnetic Flux Density (µT)			
		Min.	Max.	Mean	S. D.
Packing Hall		0.155	1.920	1.103	0.581
Tower Detergent Factory	Ground Floor	1.684	23.968	14.128	11.368
	First Floor	0.577	1.802	1.201	0.613
	Second Floor	0.328	2.506	1.708	0.951
	Third Floor	1.276	1.653	1.465	0.267
	Fourth Floor	2.415	2.428	2.422	0.009
	Fifth Floor	1.922	1.996	1.959	0.052
	Sixth Floor	2.145	2.546	2.345	0.201
	MCC Room			1.775	

Considering the mean values relatively, the Tower Ground Floor gave the highest value with highest standard deviation both for the electric and the magnetic fields. This is followed by the Tower Fourth Floor both for the electric and the magnetic fields. For the electric field, the lowest mean value is in the Tower Third Floor, while for the magnetic field, the lowest mean value is in the Packing Hall.

Comparing the maximum and minimum values measured within all the buildings considered with the ICNIRP reference values, it can be concluded that the levels of electric and magnetic fields due to mains current within the buildings are within safe limit.

As recommended by Seyhan *et al*., (2013), periodic EM field exposure measurements should be done to obtain more detailed understanding of workplace exposures and their sources, and workers/operators should be aware of EM field levels to protect their health [1]. Therefore, every factory should be carrying out this type of evaluation periodically to ascertain the level of electric and magnetic fields in their immediate environment so as to be sure that they are always within safe limit.

V. CONCLUSION

Measurements of indoor power frequency electric and magnetic fields within the premises of PZ Cussons Nigeria PLC, Ikorodu factory, Lagos was carried out. Comparing the values obtained from the measurements with the ICNIRP's Occupational reference value for safety, the results have established that the level of ELF electromagnetic fields within the PZ factory premises is within safe limit. Therefore, it can be concluded that personnel within the factory are within the safe limit of exposure.

Also, the nature of the electrical appliance being used in the factory greatly affects the level of the fields within. This can be observed from the high values obtained in the Tower Detergent factory where high rating operational electric motors are being used.

It is recommended that every factory should be carrying out this type of evaluation periodically to ascertain the level of electric and magnetic fields in their immediate environment so as to be sure that they are within safe limit always.

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