Occupational Lead Exposure in Printing Presses: An Analytical Approach.

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ABSTRACT

Lead absorption poses a great threat to the health of workers in printing presses where commercial publishing is done. A case example is the commercial printing operations in Lagos, Nigeria. Since regular exposure to lead dusts could result in lead poisoning, complications that could cause death of victims, monitoring and controlling lead absorption of operators is essential for the maintenance of workers' health and for the avoidance of the risk of incurring heavy losses due to litigation. The purpose of this paper is to model the process, rate, and quantity of lead absorption in operators of printing presses.

Measurements of lead absorption are made and compared to standards in individuals for control purposes. Two approaches are used. The first shows the risk of being poisoned by lead. The second approach relates lead poisoning to the rates of intake of lead into the body and its elimination out of the body. This model viewed the absorption of lead as a cycle and applied the continuity equation to this cycle.

(Keywords: printing press, small enterprises, daily intake, elimination rate, blood lead, lead, Pb, poisoning, occupational health, Nigeria)

INTRODUCTION

In Nigeria, printing enterprises share similar characteristics with those in other developing countries in Africa, Asia, and the rest of the world. Usually, many printing businesses occur on a small-scale, are geographically scattered, and located across major commercial cities. For example, in Lagos Nigeria, a large concentration of these small-scale printing businesses are located in the areas of Somolu, Agege, and Mushin which are short distances to the concentration of multinationals and local industries which have their headquarters in Lagos. Such companies require printing services for the production of several documents both for daily transaction and non-frequent activities. Some of these services include advertisement and product packaging. Thus, printing is lucrative business in many of these commercial nerve centers of Nigeria. Unfortunately, a large number of small/medium-scale enterprises (SMEs) still engage in the traditional processing activities that have long been identified as occupationally hazardous. Of particular concern to the current investigators is the improper usage and handling of poisonous substances and materials such as lead, which are used for printing purposes.

In these SMEs, operators usually inhale some of these substances in quantities that may be hazardous to human health. In other situations individuals may swallow such substances through food consumed in the printing environment (Twyman, 1970). Despite the seriousness of these problems, it appears that little documentation exists on lead exposure research, in particular, quantifying the amount of lead absorbed into the body by operators in printing presses. If such valuable information are provided, occupational health inspectors would be able to effectively monitor and control such unattractive incidences. This work is motivated to contribute to the current discourse on lead absorption in printing presses. In particular, a mathematical model is presented that would guide in evaluating particular amount that are consumed by the operator (Basmadjian, 1999; Krishna-Murthy et al., 1988).

THE PRINTING PRESS AND LEAD POISONING

Printing, the age-old process of producing texts and images on paper using a printing press, is an essential part of publishing that utilizes lead

which proved to be more suitable for printing than clay, wooden, or bronze (Steinberg, 1996).

Printing is one of the line of businesses that have traditionally had a high occupational exposure to health hazards (Cherry et al., 2001). The lead used for printing is made from an alloy of lead, tin, and antimony. It is the lead contained in this alloy that is of interest in this paper (Blaskette and Boxal, 2001; Sinha et al., 1993; Murthy et al., 1990; Krishna-Murthy and Sridhara Rama Rao, 1992).

The initiative of measuring the lead absorption in operators, and relating lead poisoning to the rates of intake of lead into the body and its elimination out of the body is motivated by reactions from all the stakeholders in printing services. Several customers have shown concern for the risk that the operator face by having direct contact with lead plates without any protective devices. First, lead is a highly toxic substance and poisonous metal that can damage the nervous system and cause blood and brain disorders. Long-term exposure to lead or its salts can cause neuropathy and colic-like abdominal pains. Lead has also been linked with dementia and schizophrenia (NHMRC, 2006). Second, most operators in printing presses work around the lead plates all day, and are exposed to lead dust from the plates which they can take-in in several ways. This may be through normal hand-to-mouth contact and inhalation, where lead dusts find its way into the nostrils and hence is taken into the body. Lead poisoning could occur through eating lead chips.

The symptoms of lead poisoning include neurological problems such as reduced intelligence quotient (IQ), nausea, abdominal pains, irritability, insomnia, excess lethargy or hyperactivity, headaches, and in extreme cases, seizure and coma. There are also associated gastrointestinal problems such as constipation, vomiting, poor appetite, weight loss, kidney problems, and reproductive problems. Health inspectors have shown concern and usually instruct printing press owners not to keep an operator on the job continuously. The reaction of the investor often is fear of the liability that may be incurred as a result of possible operator's death or critical illness. Thus, all these pointers are strong indicators to the need to embark on the current study.

A brief review of relevant literature is hereby given. Cherry, et al. (2001) investigate occupational exposure/infertility links in patients. It was concluded that exposure to organic solvents is common both at work and in recreational pursuits and that efforts should be made to identify the compounds hazardous to male fertility, and if the risk is confirmed, to regulate their use.

Rajah and Ahuja (1995, 1996) in two series of studies investigated lead exposures in printing press workers. In the first attempt, Rajah and Ahuja (1995) evaluated the geneotoxicity of a combination exposure of lead and smoking in workers from the printing industry and also examined the possible interactions between the two agents. The study shows that lead-exposed individuals had a significant increase in the frequency of sister chromatid changes. Further, double-exposure to smoking and lead inhibited mitosis.

In a second study by Rajah and Ahuja (1996), the authors evaluate the genotoxicity of a double-exposure to alcohol and lead in subjects from the printing industry, and the possible interaction between the two agents. Alcohol consumers had a significant increase in the frequency of sister chromatid exchanges (SCEs) compared to the controls. Though there was an increase in the frequency of chromosome aberrations and SCEs in individuals exposed to lead, it was not significant. Statistical analysis did not reveal an interaction between alcohol and lead in either assay.

Murthy, et al. (1990) report a morbidity survey relating to lead toxicity among workers engaged in letter press printing work using techniques of clinical examination of workers and estimation of blood lead and urine lead in their blood and urine samples. The results indicate higher blood and urine lead levels recorded among study group as compared to the age and experience matched control group.

From the limited studies on lead absorption in printing press workers, it seems that analytical approaches in the measurement of blood lead levels have not been explored, particularly in the developing country, Nigeria. This is necessary since without accurate and reproducible measurements, it is difficult to monitor and control the blood lead level in printing workers. The need to close this important gap has motivated the current study.

The sections that follow are divided into: methodology, discussion, and conclusion. The methodology discusses two approaches utilized in solving the blood level monitoring problem. These approaches are consequently complemented with case study illustrations that verify the application of the developed formulae in the early parts of Methodologies I and II. This approach of methodology/case study is taken in order to ensure an adequate flow of thoughts presented in the work. The section on methodology is then followed by discussion, which explains some issues, and the implications of the approaches presented in practice. The paper then closes with concluding remarks.

METHODOLOGY

This section shows how the study was undertaken, the variables that were assessed, and the evaluation techniques. Basically, two techniques are employed in order to define the solutions to the problems formulated. The first technique, referred to as Methodology I, investigates into production of enzymes from food eaten. In the presence of lead, the lead substance mimics the enzyme production process to produce a different compound thus creating a problem (Figure 1).

The second technique, termed Methodology II, models the absorption process as a cycle in order to determine the concentration of lead in the body (Figure 2). These techniques are now discussed in detail.

Methodology I: Production of enzymes

In order to illustrate this methodology, consider a protein, say PR, which is responsible for the production of an enzyme, EZ, which is necessary for the division of brain cells. Now, assume that this protein reacts normally with calcium (Ca) from food eaten in the following reaction:

$$Ca \longrightarrow Ca^{+2} + 2e^{-} \quad \textbf{(1)}$$

$$uCa^{+} + \upsilon PR \longrightarrow wCaPR \quad \textbf{(2)}$$

where u, υ and w are numeric constants.

The above equation is a normal reaction where u units of Ca^{+} combine with υ units of PR to produce w units of combined CaPR. Now, consider an abnormal reaction, where lead is present in the blood. This lead has the tendency to mimic calcium, and it reacts with the protein to produce a slightly different compound. Assume that this chemical reaction is as shown below:

$$2uCa^{+} + \upsilon PR + \gamma Pb^{2+} \longrightarrow wCa_2PbPR \quad \textbf{(3)}$$

The symbols u, υ and w are numerical constants. However, lead (Pb) undergoes the ionic reaction shown as:

$$Pb \longrightarrow Pb^{2+} + 2e^{-} \quad \textbf{(4)}$$

Now, if the lead in Ca_2PbPR reacts with oxygen in the blood, it could form a strong oxidant, lead oxide (PbO_2), which is very toxic and affects the nervous system. This is the pollutant that enters the blood stream of the printing press operator. The reaction that occurs is as follows:

$$wCa_2PbPR + 2wO^{2-} \longrightarrow w(CaPR)^{2-} + wPbO_2 \quad \textbf{(5)}$$

Now, if we assume that the original compound formed by calcium (Ca) and protein, PR(CaPR), as shown in Equation (2) undergoes a series of complex chemical reactions to form enzyme, EZ, with certain DNA characteristics (these complex DNA characteristics are left to chemists and biologists for further analysis), the presence of lead in this compound alters these DNA characteristics, hence leading to a totally different and harmful enzyme.

From Equation (5), the compound Ca_2PR^{2-} is anionic instead of the neutral compound, CaPR, which is should have been originally.

From the foregoing, two possible causes of poisoning have been established. These are: (i) the toxic oxide, $wPbO_2$, and (ii) the anion $w(Ca_2PR)^{2-}$.

This shows that depending on the value of the above constant, w, there will either be a large number of lead oxide molecules and $(Ca_2PR)^{2-}$ ions in the brain. This value, w, will determine the severity of the damage that will be done in the brain. The value of w in turn depends on the values of u, υ, and γ as shown in Equation (3) i.e.:

$$2uCa^{+} + \upsilon PR + \gamma Pb^{2+} \longrightarrow wCa_2PbPR \quad \textbf{(3)}$$

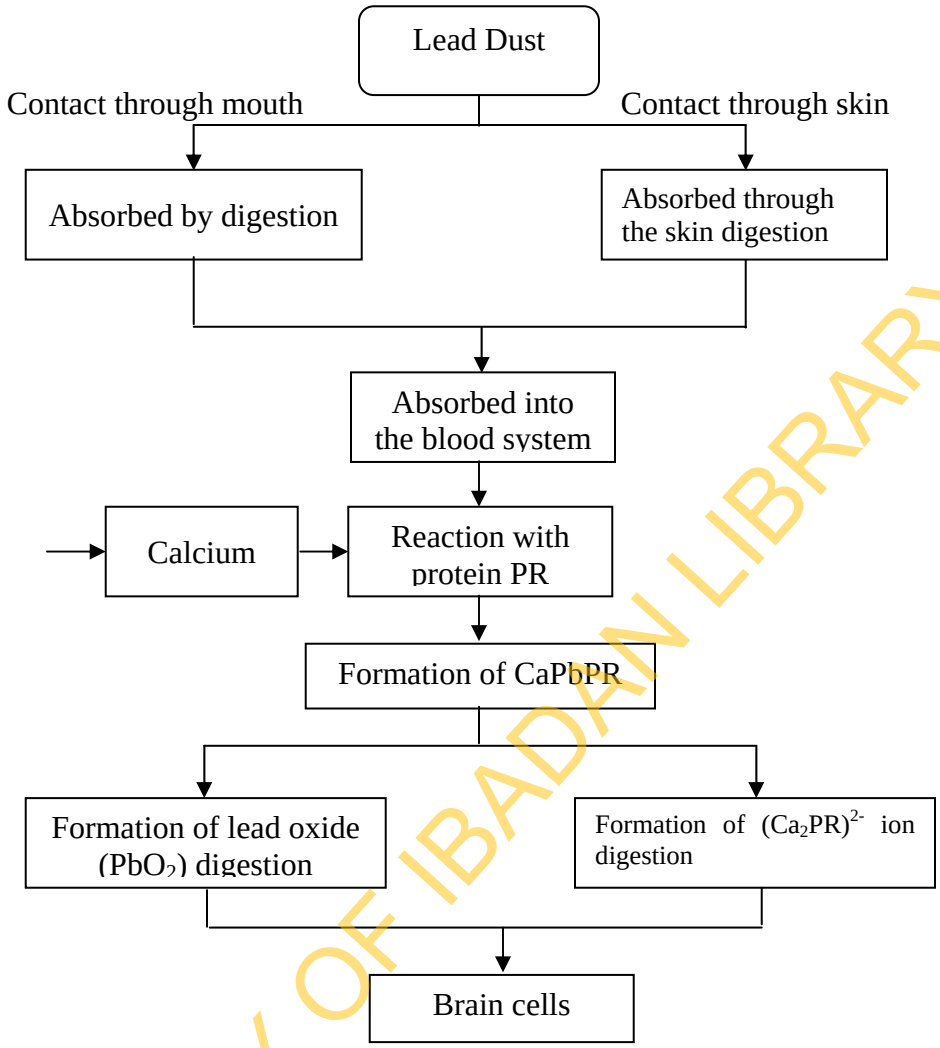

Figure 1: Movement of Lead through the Body, and the Reactions Between Lead and Other Substances in the Body.

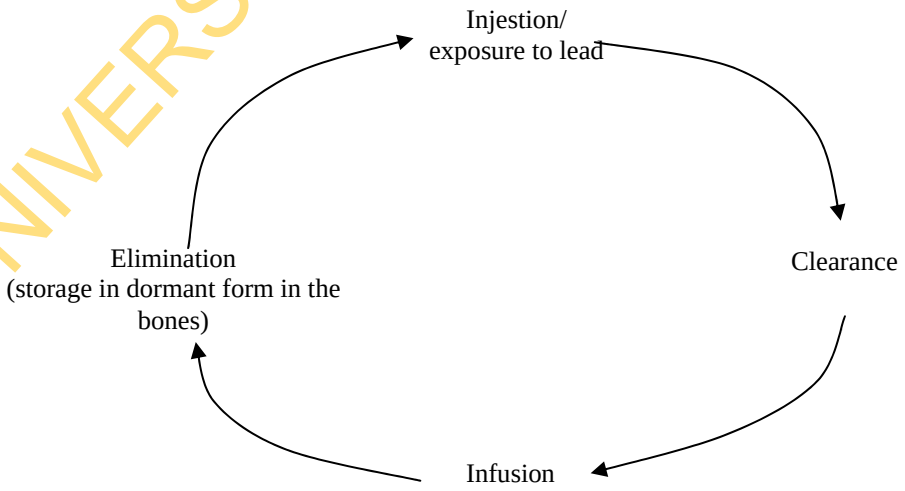

Figure 2: Cyclic Consideration of Lead Absorption Process in Operator.

From this Equation (3), it is observed that if the value of u is larger than the value of γ, more molecules of CaPR are formed than Ca_2PbPR. Also, depending on the ratio of u to γ, the CaPR molecules could either nullify the effect of the Ca_2PbPR or their presence could be negligible as compared to that of Ca_2PbPR molecules.

It is important to verify the equations in a real life case study in order to demonstrate the practical application of the concept proposed here. Case study 1 shown below is a good illustration of the ideas presented above.

Case Study 1

Consider two young city and guide (C and G) professionally-qualified operators – Mr. X and Miss Y – who work for an organization named Nigerian Printing Press (NPP). This small-scale organization employs 10 workers and is located in the business district of Somolu Local Government, Somolu, Lagos. These operators work on two different printing presses. On a certain day, they are both exposed to the same amount of lead dust. However, as a preventive measure to inhaling lead, Miss Y was careful to wash her hands before eating during her lunch break. Unfortunately, Mr. X did not since no stringent conditions or rules were in place in the organization concerning personal hygiene of workers during and after work.

Miss Y, also took a bath before going home that evening at the enterprise's bathroom, which is in the same compound. It is observed that due to precautions taken over time by Miss Y, the value of γ in her blood lead was 2, While Mr. X was 6.

Now, assume that both Mr. X and Miss Y ate a meal containing vegetables in the canteen. Mr. X, being a fat man, ate a larger portion of the food than Miss Y, and hence, the value of u in his meal was 4 while that of Miss Y was 2.

With the above data, the equations developed previously could be used to find out which of Mr. X or miss Y is in greater danger of lead poisoning.

For Mr. X, u = 4, and γ = 6. These values could be inserted into Equation (6), as shown below:

$$24\,Ca^{+} + 2PR + 6Pb^{2+} \longrightarrow wCa_2PbPR \quad \textbf{(6)}$$

Here, it is assumed that the value of υ in an average person's body protein is 2. However, by balancing Equation (6) the following is obtained:

$$24Ca^{+} + 12PR + 12Pb \longrightarrow 12(Ca_2PbPR) \quad \textbf{(7)}$$

It is obvious that from Equation (7), the value of w is 12. This means that 12 molecules of PbO_2 and $(Ca2PR)^{2-}$ will be formed. Since for Mr. X, the value of γ is larger than that of u, more molecules of Ca_2PbPR are formed than those of CaPR. The ratio of u to γ is 4:6, (i.e. 2:3), implying that Ca_2PbPR molecules will nullify the effect of CaPR in his blood.

For Miss Y, u = 2, γ = 2. Thus, Equation (3) becomes:

$$2(2)\,Ca^{+} + 2PR + 2Pb^{2+} \longrightarrow w\,Ca2PbPR \quad \textbf{(8)}$$

Thus, by balancing Equation (8), the following are obtained:

$$4Ca^{+} + 2PR + 2Pb^{2+} \longrightarrow 2Ca_2PbPR \quad \textbf{(9)}$$

From equation (7), the value of w is just 2 as compared with 12 of Mr. X. This implies that just 2 molecules of PbO_2 and $(Ca_2PR)^{2-}$ will be formed in her blood. Her susceptibility to lead poisoning is much lower than that of Mr. X. Also, the ratio of u to γ in her blood is 2:2, which gives 1. Despite the fact that the value of w is very low, this ratio is not attractive for a safe level of lead in the blood. It gives a 50 to 50 chance of being in danger or of being healthy.

Methodology II: Measurement and Cyclic Consideration of Lead Absorption Process

In order to understand Methodology II, it is necessary to first illustrate the movement of lead through the body and the reactions that go on between lead and other substances in the body. A further understanding of Methodology II is aided by considering a simplified cyclic consideration of the lead absorption process. Final information that would further aid understanding of Methodology II is the definition of a set of terms in measurement that guides the measurement activity of Methodology II.

Definition of terms

The following are international standards of measurement of lead in the body (Table 1):

Table 1: Definition of Terms.

1.	*Acceptable Daily Intake (ADI)*: ADI is a measure of the amount of a specific substance, usually in food or drink that can be ingested without appreciable health risk (WHO, 2006).
2.	*Blood Lead Level (BLL)*: One measure of lead in the body is the blood lead level measured in micrograms of lead per deciliter of blood (μg/dL) (CDCP, 2006).
3.	*Ingestion*: the process of taking in the lead into the body.
4.	*Clearance*: Here, it is assumed that the blood has reached a near uniform level that exposure has ceased.
5.	*Infusion*: This is a continuous influx of the lead.
6.	*Elimination*: This is the assumption that some of the lead leaves the body.

From the basic principles of inorganic chemistry, it is known that the concentration of a substance may change with time. So, the starting point in the development of equations for Methodology II is to plot a graph of concentration (C) of lead in the body against time. This gives the graph in Figure 3.

From Figure 3, it is understandable that the concentration of lead either in the environment or body against time changes results in rate measurement. Thus, mathematically, it could be stated that:

Rate of lead in – Rate of lead out
= Rate of change in lead content **(10)**

This means that the rate of absorption of lead into the human body minus the rate at which lead is lost from the body to the environment gives the actual rate at which lead is retained in the body. From the graph, it is observed that time changes from 0 (origin) to t. Now, starting from time t = 0, equation (10) can be interpreted thus:

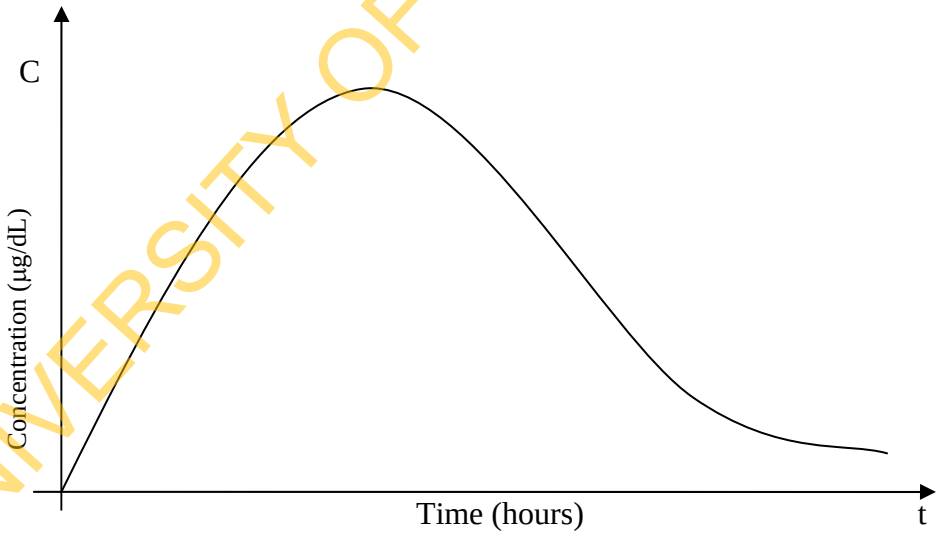

Figure 3: Concentration of Lead in Blood versus Changes in Time.

$$Q - Vk_eC = V\frac{dc}{dt} \quad \textbf{(11)}$$

where K_e is the rate constant of elimination
V is the volume of distribution
K_eC is the rate of elimination
Q is the flow rate of lead in the body

By separating the variables, integrating them, and obtaining the value of the elimination rate constant, K_e, the following is obtained:

$$-K_e = \frac{(\log C)\times 2.303}{t} \quad \textbf{(12)}$$

Now, applying the flow rate concept to the lead absorption process, it is noted that the flow rate is the rate of change of the concentration. Thus, $Q = \frac{dc}{dt}$ is substituted in Equation (11) to yield:

$$\frac{dc}{dt} = \frac{-Vk_eC}{v}; \text{ and } Q = -K_eC \quad \textbf{(13)}$$

Equation (13) expresses the rate of passage of lead into the blood through the walls of the blood vessels. This process is diffusive.

Now, taking the body as an open thermodynamic system and the blood as the working fluid, applying the continuity equation (Alcock, 2001):

$$\dot{m} = \frac{\upsilon A}{V} \quad \textbf{(14)}$$

where $\dot{m}$ is the mass flow rate of lead
υ is the velocity of lead in the blood
A is the area of the blood vessels
V is the volume of distribution of lead.

The rate equation in (10) could become: $\dot{m} - K_e = Q$, thus,

$$\frac{\upsilon A}{V} - \frac{\log C\times 2.303}{t} = Q \quad \textbf{(15)}$$

From Equation (15), it becomes clear that the flow of lead in the body would depend on the mass flow rate of lead and the rate of elimination of lead from the body. However, the mass flow rate would also depend on the velocity of blood, the area of blood vessels, and the volume of lead (i.e. the volume of the exposure to lead, namely if a person works for x hours in a day, and is exposed to y μg of lead per day).

However, the maximum level of blood lead is 10μg/dL of blood, according to the health authorities. This implies that:

$$\frac{\upsilon A}{V} \le 10\mu g/dL \quad \textbf{(16)}$$

Equation (16) gives the acceptable daily intake of lead (ADI).

Case Study 2

This case illustrates a measurement activity in which the blood lead level (BLL) of a particular worker is measured and compared with the standard set to determine if it is below standard or not. The employee concerned works for the Ibadan Printing Press, and is named Miss O.O. Health workers from the World Health Organization (WHO) paid a visit to the company, and in a random selection, Miss O.O. was picked along with 49 other employees so as to carry out a survey on lead absorption and poisoning. On this particular day, her blood samples were taken over a 15-hour period and the following data was obtained (Table 2).

Table 2: Blood Lead Level Measurement over a 15-hour Period.

Time (hours)	C (μg/dL)
3	87.5
6	68.4
9	53.3
12	28.1
15	20.6

The table shows the subject's blood lead concentrations in intervals of 3 hours, starting from 3rd hour to the 15th hour. In utilizing this data, the analyst should recall Equation (12), and substitute the values of C and t at a particular point to obtain a value for K_e. Based on this, the value of K_e and C are also substituted into Equation (13). The value of Q obtained is now substituted into Equation (15) in order to find out

the equivalent value of $\frac{\upsilon A}{V}$. This particular value of $\frac{\upsilon A}{V}$ is the measure that is compared against standard to decide if the BLL is less than, equal to, or greater than the set standard by the monitoring agencies. As an illustrative example, the values of BLL after 12 hours is utilized. First, Equation (12) is recalled, and the value of K_e calculated as:

$$-K_e = \frac{\log C \times 2.303}{t} = \frac{(\log 28.1) \times (2.303)}{12} = 0.278 \cdot$$

Substituting the value of $-K_e$ and C into Equation (13) gives: Q = 0.278 x 28.1 = 7.81.

Now, by substituting the values of Q and $-K_e$ into Equation (15), the following is obtained:

$$\frac{\upsilon A}{V} - 0.278 = 7.81,$$

which gives $\frac{\upsilon A}{V} = 7.81 + 0.278 = 8.088$.

The value of 8.088μg obtained is then substituted in Equation (16) in comparison with the value on the right hand side of the expression. In this particular example, substitution gives 8.088 < 10μg. This condition is satisfied as the calculated value of 8.088μg is less than the standard of 10μg. It may therefore be concluded that at the instant of measurement (i.e. 12 hours), Miss O.O.'s Acceptable Daily Intake (ADI) has not been exceeded and her blood lead level is below the set standard. Hence, Miss O.O.'s condition is acceptable to the health authorities. However, it needs to be controlled.

DISCUSSION OF RESULTS

From Equation (3), it is obvious that the value of u has to be higher than that of γ for one to have an acceptable blood lead level. In the first case study, running Mr. X's data through the model showed that he was at a risk of being poisoned by lead. Miss Y. on the other hand was discovered not to be as safe as it apparently seemed.

The second model was able to relate lead poisoning to the rates of intake and elimination of lead into and out of the body. This model took the absorption of lead as a cycle and applied the continuity equation to this cycle.

CONCLUSION

This paper addresses matters that relates to organizational safety, health, and the environment. Consequently, safety and health professionals, governments, and all the stakeholders in the printing business, should favorably view this paper. The paper is an attempt at addressing the lead absorption problem that poses a great threat to the health of workers in printing presses. In particular, the paper models the process, rate, and quantity of lead absorption in operators of printing presses.

The second part of the paper relates lead poisoning to the rates of intake of lead into the body and its elimination out of the body. These efforts are to avoid associated lead poisoning gastrointestinal problems such as weight loss, kidney problems, and reproductive impairment. The methodology employed shows how the study was undertaken and assesses variables that relate to acceptable daily intake, blood lead level, and elimination rates. Basically, whichever way the examination is approached, it still remains a fact that lead absorption is a hazard to health and needs to be curtailed.

This research has implications and consequences for small-scale printing enterprises. First, in view of the small size of the printing organizations studied, adequate care must be taken to guard against direct contact or exposure of operators to lead. As such, lead plates must be handled with gloves, and the environment well ventilated. Management must ensure strict adherence to this instruction with adequate penalties imposed on defaulters.

Continuous training and enlightenment on lead-handling techniques should be carried out. The management should be aware that the liability cost incurred for an operator whose health is failing as a result of lead poisoning is higher than the preventive cost incurred on enlightenment and house cleansing/environmental activities.

Since it is unlawful to retain an operator on the job that exposes him to lead for a long time, skill transfer programs should be utilized for job continuity in the printing organization. It should be noted that regular medical checks to observe the possible level of lead in the blood and the application of the models developed here are essential.

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