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THE SAWDUST INHALATION PROBLEM IN A SAWMILL ENVIRONMENT

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ABSTRACT

The sawmill literature has diverse studies on sawmills in terms of safety, health and environment. Despite these numerous studies, investigations that relate to sawmill environments, activities and the human interface are scarce. Therefore, this paper bridges the gap by modelling the possible effects of sawdust on employees working in sawmills. A scientific explanation on sawdust particle theory within the context of workplace health and safety is attempted. Two approaches to solving the sawdust inhalation problem are discussed: (1) the volume and concentration of sawdust in the sawmill environment is related to mass inhaled by workers; and (2) the presence of long-lived carbon radioactive in wood was matched to the effective dose inhaled by workers. The framework presented is supported by drawing evidence from a case study that illustrated the effects of dust on workers based on a standard set of work for sawmill workers. This study may be of interest to managers in sawdust mills, furniture industry, safety, and health, and environment workers interested in monitoring occupational health.

Key words: Sawdust particles, environment, safety and health, Nigeria

1. INTRODUCTION

Sawdust particles are fine grains of wood formed during the cutting or sawing process in sawmills. Although sawdust are of economic and experimental benefits in serving as absorbents and sorption materials (Hamdaoui, 2006, Šćiban *et al*., 2006; Hamadi *et al*., 2001; Jadhav *et al*., 2004; Taty-costodes *et al*., 2003), studies on sawdust, among other hazardous substances, have been the concern of a great number of researchers with interests in quantifying occupational exposures of workers (Arif *et al*., 2003) and in defining exposure limits (Demers *et al*., 1997). For example, Hamid *et al*. (1965) identified the volatile fatty (i.e. acetic, propionic, butyric, isovaleric, n-valeric, isocaproie, and n-caproic) acids present in hickory sawdust smoke. Consequently, sawmills are extremely hazardous work environments due to wood processing, which generates sawdust that have adverse effects on workers in sawmills. Thus, sawmill workers are exposed to a variety of respiratory hazards through their contact with sawdust, which may follow one or more of the following pathways: inhalation, dermal, ingestion, and optical exposure. Although the actual component of the sawdust which causes harmful effects on humans cannot be properly ascertained, the wood from which the sawdust is obtained could be said to contain biologically active organic compounds (such as monoterpenes tropolones, resin acids, fatty acids, phenols, tannins, flavinoids, quinines, lignanes and stilbenes/air borne moulds and bacteria, radioneclides and preservatives such as formaldehydes, etc.), which affect humans.

The sawmill literature has however provided some useful insights into the contention that sawmill workers are at risk. These primarily concern the effects of emission of volatile compounds from stored woods on sawmill worker (Svedberg *et al*., 2004), the risk of childhood cancer by children of sawmill workers through their paternal exposure to harmful substances (Heacock *et al*., 2000), dermal exposure to hazardous substances (Erikson *et al*., 2004), and prevalence of asthma in sawmill workers (Siracusa *et al*., 2007). The particular details of the above review are now given. Svedberg *et al*. (2004) investigated the emission of volatile compounds, particularly hexanal and carbon monoxide, from large- and small-scale storage of wood pallets. Such storage systems are predominantly found in sawmills. Heacock *et al*. (2000) established a relationship between the risk of childhood cancer and paternal occupational exposure to chlorophenate fungicides in British Columbian sawmills. Erikson *et al*. (2004) evaluated dermal exposure to the resin acids abietic acid, dehydroabietic acid and 7-oxodehydroabietic acid during collecting in sawmills. Siracusa *et al*. (2007) evaluated the prevalence of asthma and its predictors in studies of several male working in 619 cedar sawmills. The prevalence of asthma after employment in the industry, as a surrogate for work-related asthma, was 3.9 times higher in cedar sawmill workers.

The effects the sawdust has on the worker exposed to it could be expressed depending on the type of exposure. For short-term exposure to sawdust, which could produce allergic reactions, the effects may not be as pronounced as for long-term exposures, which can cause chronic respiratory disease. The ways in which sawdust comes in contact with humans so as to cause adverse effects are by inhalation, contact with the eyes, contact with the skin, etc. In general, the effects on the health of the human due to exposure to sawdust are: (1) decrease in lung function due to mild irritation of the nose, lungs, etc.; (2) redness of eyes; (3) general discomfort, etc. Also the nature of the wood could determine the effect on the person, e.g. occupational asthma has been found to be associated with exposure to sawdust from African maple. African zebra, ash, California redwood, cedar of Lebanon, central American walnut, eastern white cedar, ebony, iroko, mahogany, oak, ramin and western red cedar, as well as other species (II). Respiratory effects on human body are also possible from exposure to chemicals used as adhesives, preservatives in the sawdust industry, e.g. formaldehyde, chloro-carbon compounds and other chemicals like arsenic compounds can cause irritation of the human system, and inflammation of the nose, throat and eyes, etc. Acute effects on lung function have also been observed and results in asthma and chronic bronchitis (I). Burning of sawdust in sawmill creates fumes which can also cause injuries in the human body. Smoke inhalation is highly severe because the particles are extremely minute and diffuse in the body system easily. This could lead to adverse effect on the lungs and make the pulmonary response slow.

From all observations, it becomes important to understand the mechanics of the particle in order to determine how much of these particles are actually inhaled by the worker while exposed to sawdust. Investigations will also assist in determining the possible effects on workers and install corrective measures in this regard. Thus, this paper is directed towards achieving the purpose of modelling the amounts of sawdust that can be inhaled by a worker in a sawmill.

The structure of the article is as follows: the introduction presents the problem, the motivation for investing financial and non-financial resources into investigating this problem and the literature review. Section 2 discusses the methodology utilized for solving the problem. The segregation of the methodology into three main parts is discussed. Section 3 presents the case study that discusses the practicality of the proposed model through a verifiable practical case. It also presents the discussion of results with explanations for the pattern of results obtained. Section 4 presents the conclusion of the study.

2. METHODOLOGY

2. 1 Notations

ρ: density of wood particles
ρ_1: density of wood particles at the entry point 1
u_1: volume of dust occupied at the entry point 1
A: area of enclosure
A_1: area of spread of these particles at the entry point 1
ρ_2: density of wood particles at the exit point 2
u_2: volume of dust occupied at the exit point 2
A_2: area of spread of these particles at the exit point 2
A_m: volume of sawdust inhaled by the worker
T: exposure time to sawdust

r: radius of the timber which produces sawdust
h: height of the timber from which sawdust is produced
u: speed of air
t: number of timbers cut
Q: flow rate of sawdust in air
Q_A: approximate total flow rate of air in the environment
F_{prod}: fraction of sawdust active in the air
A_{inh}: amount of sawdust inhaled in the lungs or respired.
F_R: inhalable or respirable fraction of sawdust in air
Q_{inh}: quantity of air that can be inhaled by a worker per unit time (ventilation rate of the worker)
V_i: volume of air inhaled
C_{der}: average concentration of sawdust in skin
C_{prod}: average concentration of sawdust produced
D: diffusion factor of sawdust
d: diffusion rate
V: volume of undiffused sawdust
Q_{prod}: amount of undiffused sawdust
α: sawdust withdrawal quantity from the sawmill
T_a: total periodic dose of carbon radioactive inhaled by the operator. This measure may be in months, weeks or days, depending on the yard stick of measurement.
R_c: radioactive activity concentration in wood.
D_{cc}: dose conversion coefficient for the inhaled substance.
E_r: periodic effective dose of sawdust.
C_{nr}: mean activity concentration of the carbon radioactive in the sawdust.
D_f: diffusion factor
D: dose rate in air at site of occupational exposure (i.e. air-dose rate).
O_f: occupational factor.
C_c: conversion coefficient from the dose into effective dose.
C_w: mean carbon radioactive activity concentration in wood.
E: total periodic effective dose
E_{ext}: total periodic effective dose (external)
E_{int}: total periodic effective dose (internal)
Cf_d: carbon radioactive concentration factor from wood to sawdust is a function of the type of wood (soft or hard), and the seasoning condition of the timber.
DR_{ext}: external dose rate coefficient.
E_{inh}: effective dose due to periodic inhalation
C_d: mean periodic radioactive activity (i.e. days, weeks, months and year)
L_p: mean periodic sawdust load. This is a function of the amount of work in the sawmill, which depends on the demand for sawn timbers by customers
BR: breathing rate is a function of the state of health of the operator at the time of study, the climatic condition in the environment (i.e. same individual may exhibit different breathing rates during rainy and sunny days), age of the operator
DH: internal dose coefficient for inhalation

In the application of particle theory to the problem of sawdust inhalation, varying volumes and masses of sawdust particles can be produced depending on: (1) the sharpness of the blade of cut (poorly sharpened blades produce coarse grade sawdust particles); (2) the type of wood being sawn (hardwoods or softwoods, and the variety in each class); (3) the speed at which the machines or cutting equipment is operated (low speed from low-powered rated equipment and potentially high speed from high-powered rated equipment); (4) age of the machines (operational efficiency of cutting machines decrease with age); (5) skill and training of sawmill operator in the control of sawing operations; and more. However, density could be a common measure for the sawdust since it rates mass of the sawdust per unit volume of the sawdust produced. This is the strongpoint for using density in the evaluation and model formulation.

The use of control volume concept is made in view of the particle theory being applied in the model. This permits boundaries at two points and measuring the densities, volumes and areas at the two different points as well as the area of enclosure. Then steady flow conditions in the control volume are then utilized to capture measures for the sawdust particle. However, in real life situations, assuming steady flow of sawdust particles may not be applicable. Thus, the unsteady flow situation exists, in which the sawdust particles demonstrate chaotic behaviour with respect to their motion in the sawmill environment. So, chaotic models are borrowed from literature to upgrade the credibility of the work and make it more realistic. Thus, the assumption that the flow of sawdust is constant may be relaxing. It is a common knowledge that given the same conditions of producing sawdust and an exposure of individuals to sawdust particle, the possible amount of sawdust inhaled by individuals in the sawmill environment varies directly with the exposure time. However, there is a maximum time above which inhalation of sawdust becomes very hazardous to health and should be discouraged. Hence, since time is variable in the operations of sawmill activities, it becomes an important variable to consider in the modelling. Eliminating time from model formulation would then leave a wide gap to be filled. Hence, this provides justification to incorporate time in modelling sawdust particle theory.

Another important variable is the number of timbers cut during the working hours. Clearly, the higher the number of timbers cut, the more the potential to having more quantities of sawdust produced. In practice, given a number of timbers scheduled for production per working hours, the sizes (in terms of diameter) of timbers produced vary. In real life, even a particular timber does not have a regular cylindrical shape. It could be tapered cylinder or a slightly fluctuating cylindrically shaped timber that the radius fluctuates according to sinusoidal behavioural curves. Thus, in analysing the wood materials, these shapes are of primary interest. However, for simplicity of modelling, the basic shape of cylinder is assumed. Since the sawdust particle is carried by the air in the sawmill environment, the speed of air is an important variable in modelling sawdust inhalation. This points to the fact that given the same conditions of operations and production of sawdust, the influence air on the mobility of sawdust particle would be different under the rainforest climatic condition as opposed to desert regions.

Consider the rainforest region of Lagos, Nigeria and the Sahara region of Maiduguri, Nigeria, for instance. Since the forest would absorb part of the air being blown in the sawmill environment as opposed to non-obstruction from the Sahara region of Maiduguri, the effectiveness of air speed is felt more in the latter than in the former location. Another variation to the speed of air is caused by the weather condition at the instance. During rainy season, there is much presence of natural air that blows the sawdust particle, compared to dry season when the wind rarely blows. This also affects the speed at which the sawdust particle is being carried. An important variable is the fraction of sawdust active in the air. This depends largely on the guarding and control system of the sawing equipment. If the sawdust removed from timber is not carefully controlled by guards at production and the dumping is indiscriminately done within the sawmill environment, then a high fraction of sawdust would be active in the air.

In modelling sawdust inhalation in sawmill workers, it is important to recognize the linkage between the human immune system and the human anatomy principles in dealing with foreign bodies. First, sawdust particles are seen as foreign bodies invading the body territory. Immediately deposits of sawdust are observed on the skin, antibodies (i.e. ‘soldiers’ protecting invasion of foreign bodies into the body) produce antigens, which fight against this invasion. This process is continuous until the antibodies are able to conquer. However, when these sawdust particles are continually deposited on the skin, the antibodies would fight to a point that they cannot cope again. At this point, sawdust could enter the skin and body (through the nose or ingestion) and invariably cause harm. This threshold at which the sawdust conquers is of primary interest to researcher. By denoting the concentration of antibodies fighting against sawdust invasion as ψ, and the maximum threshold that the body could produce as ψ_{max}, then antigens are a force (negative) reducing the effects of sawdust invasion into the body.

Modelling sawdust particle inhalation, ingestion or assimilation into the body is significantly affected by the use or otherwise of protective wears (safety goggles for eye protection against sawdust particles, nose protectors and general work clothing). In societies where sawmill activities are regulated with safety requirements imposed on workers, the use of protective wears would drastically reduce the sawdust particles inhaled, ingested or assimilated, since deposits of sawdust particles noticeable on wears are easily cleaned up. These masses represent the quantity that was to have been ingested.

It is important to emphasize that loss of sight or suffering other temporary or permanent disabilities while working in a sawmill is a common occurrence (Pickering *et al*., 1972; Terho *et al*., 1980). Hazardous as the work environment is, in many sawmills, workers are not availed of adequate protective clothing. There is no safety boot, no appropriate mask to save workers from the sawdust particle, which contains carbon radioactive, and toxins, and no eye goggles. Sometimes all they are given is hand gloves, which make no difference when handling very heavy and slippery logs. Moreover, torn hand gloves that do not protect are still being used.

2.2 Assumptions

The literature on sawmills has related sawdust to a number of outcomes: (1) inhalation, (2) dermal exposure, (3) ingestion, and (4) optical exposure as primary paths through which sawdust could affect humans (Svedberg *et al*., 2004). However, items (3) and (4), which relate to accidental swallowing (especially in large quantities) of sawdust, and sawdust contact with the eye (that leads to increased prevalence of eye irritation, discomfort and abrasive eye inflammation) are assumed negligible in the overall occurrence. This is because it is expected that any worker in a sawmill should be familiar with all the details of the job before being given the responsibility of producing sawn timbers. Consequently, the worker is expected to clean up and particularly wash hands immediately when leaving the production floor or going to eat. Hence, the possibility of ingesting sawdust is reduced to the minimum. Also, care should be taken against optical exposure by the worker since he or she is expected to be educated and trained about the dangers of exposing eyes to saw dusts through the use of safety goggles. Thus, efforts are focused on the first two items. Before proceeding, it is necessary to state the assumptions under which sawdust could be treated as flowing fluids:

1. The sawdust particles are in a steady flow and evenly distributed in the air. This assumption is to guide against complexity that may arise if the flow is defined otherwise. Also, uneven distribution of the particles of sawdust in the air may warrant capturing movements with random characterization tools, which would complicate the initial analysis presented here to establish the proposed approach. In this paper, the particular flow considered in the sawmill environment has been treated as non-chaotic for the purposes of simplicity. The motivation for this assumption is that until a study actually measures sawdust flow in a sawmill environment, the extent of the chaotic flow may be difficult to evaluate. It should be noted that we assume reasonable ventilation in this case since most sawmills in Nigeria have fairly good ventilation around the sawmill environments.

2. The second assumption states that the immediate environment enclosing the worker is taken as the control volume. For ease of analysis, control volume, which represents and arbitrary volume fixed in space through which fluid flows, can be applied to the movement of sawdust particles. This is based on the premise that the identity of the sawdust particles occupying the control volume changes with time (Yahya, 2006). Binding the workers' environment assists in having a defined area in which analysis is restrained to. This is typical of solving physical problems so that the area of worker's environment could be suitably adjusted to the desired conditions.

3. The third assumption states that the volume of sawdust inhaled by the worker is directly proportional to the exposure time. That is $A_m \alpha T$. This makes sense, since shorter time to exposure of worker to sawdust indicates lower quantity of sawdust inhaled, and the other way round, the longer the period of exposure of worker to sawdust, the higher the quantity inhaled. However, the specific relationship, which could be linear, quadratic, exponential, logarithmic or a combination of functions may need to be determined.

2.3 Theoretical framework

There are different situations, principles and concepts that impact on the modelling of the sawmill inhalation using the particle theory. One of these exists within the control volume analysis when collision between sawdust particles prevails. This will certainly change the velocity of motion of sawdust particles when the masses may be united until the two collided particles hit the walls of the control volume. This effect is treated as negligible. A second situation relates to the effect of climate on the motion of the sawdust particles in the air and the consequent speed of the particles when the sawmill operator inhales them. Thus, the suspension of sawdust in the sawmill environment has significant interactions with climate, particularly with respect to modelling sawdust inhalation by sawmill workers. Consequently, changes in results are expected when the inhalation modelling parameters may be considered. Two sets of climate-related independent variables are concerned with sawdust inhalation modelling-primitive variables such as temperature, relative humidity and wind speed, and derived variables including cooling degree days, heating degree days and enthalpy latent days. For model simplicity, the effect of climate changes and climate variability on inhalation of sawdust and in particular when the sawdust particles contain carbon radioactive is assumed negligible.

Methodology 1

The methodology adopted here hinges on the principle of flow of fluid, adapted for sawdust particles, based on the theory of fluid mechanics and thermodynamics of particles. This is well supported by Eastop and McConkey (1994), Rogers and Mayhew (1992), and Douglass *et al*. (2005). Here, the sawdust particles obey particle theory in which they move in a constrained volume that is referred to as control volume, which is similar to a pipe terminated at two ends 1 and 2 (Figure 1).

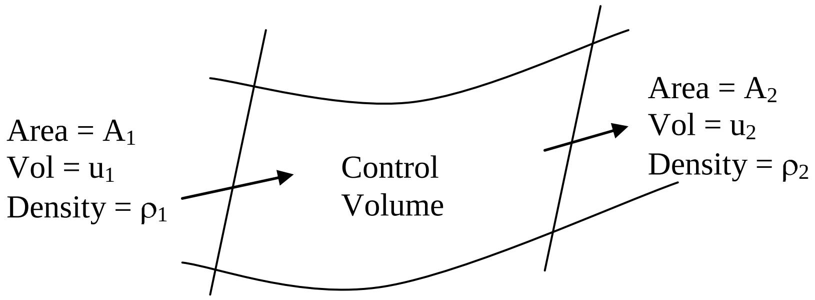

Figure 1. *The control volume*

In this situation, the sawdust particles are assumed to be in steady flow. This is supported by the fact that for the operational periods of a sawmill, the sawdust particles are continuously produced from wood, and scattered all over the environment. Although at rest periods of workers, the flow may be discontinuous, these intermittent stoppages are considered short and infrequent enough to knock out the assumption of continuity of sawdust particles in the sawmill. When sawdust is produced, in view of its porous property, it could change in mass per unit volume when considered at two points. This means that the air will enlarge the sawdust size. The sawdust particles are assumed to be of a changing density from one point to another. For example, if the sawdust particles are trapped within a control volume (Figure 1), then at the entry point, the density is ρ_1, the volume of dust occupied at the entry point is U_1, while the area of spread of these particles at the entry point 1 is A_1. Similarly, by changing the subscripts to 2, the density, volume, and area of the sawdust at point 2 change to ρ_2, U_2 and A_2, respectively.

The sawdust particles are carried freely in the air, and it appears that the principle of conservation of the momentum of the sawdust participles that collide, which makes constant the product of mass and velocity of colliding sawdust particles both at the entry and exit points of the control volume, is applicable. This principle states that the mass of sawdust particles and its velocity entering the control volume per unit time is the same as that of leaving the control volume per unit time. Remember that mass is computed from the multiplication of density of area of exposure of sawdust particles, and the velocity of the sawdust particles, which is driven by air.
Consequently, for the control volume in Figure 1,

$$\rho_1 A_1 U_1 = \rho_2 U_2 = \text{Constant} \quad (1)$$

Since the equation (1) represents mass, denoted by M, we now have

$$M = \rho AU \tag{2}$$

There are two scenarios that now exist for the sawdust particles: incompressible and compressible states. If the sawdust particles are assumed to be compressive (which may be the subject of another research), then a complexity of computation exists. However, for computational simplicity, the sawdust particles are assumed to undergo in compressive flow, which implies that the density at the entry and exist points (P_1 and P_2, respectively) of the control volume is the same. That is, $\rho_1 = \rho_2$, which implies that equation (1) could be reduced to $A_1 U_1 = A_2 U_2$, and stated generally as:

$$Q = AU \tag{3}$$

Here, Q is the flow rate or volume rate of sawdust particles in air (measured in m^3/s), and is considered for an ideal fluid with velocity U, and cross-sectional area A. Now, if U is the velocity of the sawdust particles at any radius r, within the control volume, the flow ∂Q through a small portion of radius r and thickness ∂r will be:

$$\partial Q = 2\pi r \, \partial U \tag{4}$$

It then means that $$Q = 2\pi \int_0^R Ur \, dr = \pi R^2 U \tag{5}$$

Here, the radius of the control volume ranges from 0 to R. Now, if we ignore the variation of velocity over the cross-section of the control volume, the velocity is assumed to be constant and is given as:

$$\text{Velocity} = Q/A \tag{6}$$

Now, the control volume needs to be linked with the amount of sawdust produced during the sawmilling operation. Here, we need to know the number of timbers sawn per day and an estimate of the mass of sawdust per timber. By finding the product of these, the desired value is obtained. The next stage is to compute the volume of a typical log of wood (timber) from which computation of the total volume of timbers in a sawmill could be made. However, for the purpose of model simplification, the timber is considered to be of a regular cylindrical shape and size, with perfect characteristic typical of a cylinder (Figure 2).

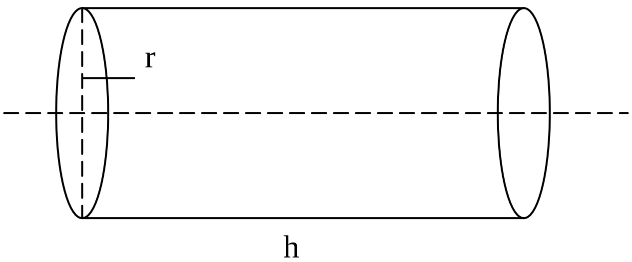

Figure 2. *The cylindrical shaped timber*

Then, the volume of timber becomes $\pi r^2 h$, where r is the radius of the timber, and h is the height of the timber. Now, let t be the number of timbers cut.

From the relationship of density as mass per unit volume, the total mass of sawdust produced is

$$Q_{prod} = m = \rho \pi r^2 ht \tag{7}$$

Now, there is need to relate the flow rate of sawdust in air to the total flow rate of air in the environment.

Then, we have: $$F_{prod} = \frac{Q}{QA} \qquad (8)$$

Now, let the volume of enclosure (i.e. the restricted control volume) be V_c, and the concentration of inhalable sawdust in the air be C_{inh}, the a ratio could be established for Q_{prod} , F_{prod} , V_c, and C_{inh} as follows:

$$C_{inh} = \frac{Q_{Prod} \, x \, F_{Prod}}{V_c} \qquad (9)$$

As the sawdust is inhaled, passing through rose, its deposits are accumulated in the lungs over time to such a threshold that the human body could no more accommodate. This is when the body reacts and breaks down. In order to calculate the total amount of sawdust accumulated in the lungs of humans over a period of time of exposure to sawdust, T, we have to know the inhalable or respirable fraction of sawdust in air (F_R), the ventilation rate of the worker (Q_{inh}), and the volume of air inhaled by human (V_i). Additional variables needed include the weight of the worker (W), and the number of days of exposure of worker to sawdust.

The starting point in the computation is to find an expression for Q_{inh}, which is quantity of air that can be inhaled by a worker per unit time (ventilation rate of the worker).
T = Duration of exposure to sawdust

Symbolically, $$Q_{inh} = \frac{V_i}{T} \ (m^3/min) \qquad (10)$$

Equation (10) could be expressed by change of terms to V_i as:

$$V_i = Q_{inh} \, T \qquad (11)$$

Therefore, $$A_{inh} = F_R \ X \ C_{inh} \ X \ V_i \qquad (12)$$

It is possible to substitute for V_i from equation (11) in equation (12). This changes to: $$A_{inh} = F_R \ x \ C_{ihn} \ x \ Q_{inh} \ x \ T \qquad (13)$$

Thus, the amount inhaled over an event or days per workers is given as:

$$A_{inh} = \frac{F_R \ x \, C_{inh} \ x \ Q_{inh} \ x \ T}{W} \ x \ N \qquad (14)$$

where N is the number of days and W is the number of workers. The unit for A_{inh} is therefore obtained as (mg/kgW/day). The above derivations express inhalation through the nose. While this inhalation through the nose is expressed by equation (14), the amount of sawdust available in the sawmill environment would be drastically reduced if users are allowed to pack the lot. The literature supports its use as new base material for boiler (Akira *et al*., 2002), concrete material (Kantautas and Vaickelionis, 2000; Udoeyo and Dashibil, 2002), domestic cooking (Ajayi and Owolarafe, 2007; Bolaji, 2005), livestock bedding (Shigeo *et al*., 2001), and substance removal agents (Ansari and Raofie, 2006). Other uses include as a nitrogen source in corn production (Brass and Foshee, 2004) and as composite materials in recycling (Najaf *et al*., 2006). Consequently, an alternative to equation (14) could be built where α is introduced as sawdust withdrawal quantity from a sawmill. Thus, the new equation becomes.

$$A_{inh} = \left[\frac{F_R \times C_{inh} \times Q_{inh} \times T}{W} \times N \right] - \alpha \qquad (14a)$$

Now, it is also known that the skin (dermal) exposure is another pathway that a sawmill workers are exposed to sawdust. The following mathematical arguments are therefore proposed for dermal exposure. The starting point is to define the component variables needed for computation of the area of dermal parts exposed to the sawdust absorption. If we assume that exposure of other parts of the body to sawdust intake through dermal means is insignificant, but only through exposed areas of the hands and arms, then the area through which intake of sawdust is possible depends on the surface area of hands and arms. This is referred to as $A_{der} = C_{der} \times V_{app}$.

But $V_{app} = \text{Area} \times T_t$ (15)

Therefore, $C_{der} = \frac{Q_{prod} \times F_{prod}}{V_{prod} \times D}$, then $A_{der} = \frac{Q_{prod} \times F_{prod}}{V_{prod} \times D} \times \text{Area} \times T_t$ (16)

By following the same viewpoint as in A_{inh} for A_{der}, the amount of sawdust withdrawn from the sawmill remains at α. Thus, there is a modification to equation (16) as:

$$A_{der} = \left[\frac{Q_{prod} \times F_{prod}}{V_{prod} \times D} \times \text{Area} \times T_t \right] - \alpha \quad (16a)$$

For determination of dermal exposure of humans to sawdust, it is important to know the total surface area of the body exposed or in direct contact with sawdust production from timber. In wood sawing environments with internal ventilation systems (indoor operations), it is usually noticeable that after working for some periods, the whole body of the operator is full of sawdust bath (i.e. face, hands, legs, etc. and this sawdust pollution is noticeable in operators who cough during and immediately after sawing operations). Thus, the concentration of sawdust on the body is aided by the limited air circulation in the environment (in view of poor ventilation system). This is opposed to working in external ventilation systems where wind and natural air could blow away the pool of dusts emanating from the sawn logs. In addition, the unlimited boundary in the external environment permits sawdust to diffuse in the atmosphere with limited volume of deposits on the body of the sawmill operator. The literature contains useful sources of computations of surface areas of human body, which could be adapted for use in the current study. Banerjee and Sen (1955) pioneered reporting on human surface area computation with application to determining the surface area of the body of Indians. The output of their research was preceded with documentation on surface area computation of cattle and swine (Hogan and Skouby, 1923). More recent documentation on surface area of humans are credited to Gehan and George (1970), Cerato and Lutergger (2002) and Lenau and Mazilli (1996).

Methodology 2

The second methodology is the consideration of how the presence of long-lived radionuclide (otherwise referred to as carbon radioactive) such as $^{137}C_5$ and $^{90}C_{58}$ which are present in wood would also affect the operator. This paper models the effective dose of sawdust containing carbon radioactive that the operator may inhale. Certainly, there is abundance of evidence that in wood carbon radioactive are present in it. These carbon radioactive may last for several years. Now, assuming that after the wood had been sawn these carbon radioactive are still present in the sawdust, then they could be inhaled together with the sawdust by the sawmill operator. Let us consider specific carbon radioactive and develop relationships of expressions for their inhalation by a sawmill operator. Thus, consider carbon radioactive $^{137}C_5$ and $^{90}C_{58}$ present in the wood sawn.

Then $D_{cc} = \frac{T_a}{R_c}$ $(ms_v bq^{-1} kg)$ (17)

where $1\ bq = \frac{1}{s}$

Also, $E_r = D_{cc} \cdot C_{nr}$ (ms_v) (18)

By substituting for D_{cc} from equation (17) in equation (18), we have a different expression as:

$$E_r = \frac{T_a}{R_c} \cdot C_{nr} \quad (18a)$$

Suppose several carbon radioactive are present to the maximum number n, where r is the counter, then from equation (14),

$$E_r = \sum_{r=1}^{n} D_{cc} \cdot C_{nr} \quad (19)$$

An alternative expression for E_r is as follows:

$$\sum_{r=1}^{n} \frac{T_a}{R_c} \cdot C_{nr} \quad (19a)$$

Now considering the dilution factor, D_f,

$$E_r = D_f \cdot \sum_{r=1}^{n} D_{cc} \cdot C_{nr} \quad (20)$$

and $E_r = D_f \cdot \sum_{r=1}^{n} \frac{T_a}{R_c} \cdot C_{nr}$ (20a)

Now, $E = E_{ext} + E_{int}$ (21)

Then $E_{ext} = D \cdot O_f \cdot C_c$ (22)

However, $D = C_p \cdot D \cdot R_{ext} = C_w \cdot Cf_d \cdot DR_{ext}$ (23)

A general expression for calculating the dose due to inhalation of air-borne sawdust containing long-lived carbon radioactive is:

$$E_{inh} = C_d \cdot L_p \cdot BR \cdot O_f \cdot \Delta H \quad (24)$$

$$C_d = Cw \cdot Cf_d \quad (25)$$

3. CASE STUDY AND DISCUSSION OF RESULTS

In order to verify the applicability of the mathematical relationships developed, a case study is drawn from a site in Lagos, Nigeria. This case study draws evidence from real life and illustrated the effect of dust on workers. Most of the time the workers, although of various grades, work together. The main activities of the workers commence from the offloading of timbers from the truck. These timbers are stacked in piles and withdrawn periodically from processing. At the offloading stage, these timbers do not constitute hazards. Also, getting them stacked and withdrawing them from processing does not constitute any sawdust generation. However, at the time of cutting these timbers, a lot of sawdust particles are generated. It is required to know how much quantity of sawdust (at different points away from the cutting blade) is produced. Information is collected on a typical day in which the level of activity in processing of logs of wood is collected. In such a practical situation, there are various conditions that would affect the results obtained from the model application. For example, since saw milling activities are carried out in the open, the effect of wind speed on the speed of sawdust particles (when blown away) may be significantly different from the condition where wind effect is not considered. What happens is that the speed of air would be excessively high to increase the speed at which saw dust particles are blown. However, for simplicity of model application, wind effect is not accounted for. Another factor is the effect of temperature range across the day on the operator who feeds in logs into the machines before saw dusts are produced. Since humans react to environmental temperature, at early periods of the day, the level of activities with respect to sawdust particles produced from sawn logs will be high compared with the level during high temperature in the day (about 13:00 hrs – 15:00 hrs) when the intense sunshine would naturally retard productivity of workers at the sawmill. In sum, for the model application, the effect of temperature, wind, and other conditions is considered negligible for the environment considered.

In this case, it is observed that a log of wood is sawn per day by the working team at a sawmill. A day's work ranges from 1 to 9 hours. Now, the flow rate is given as $Q = 3\ m\ s^{-1}$ (Yang and Li, 2009). An average timber has varying shapes, which may resemble a cylinder. In order to verify the application of the model developed in the earlier section, the various shapes are approximated to cylinders (since it is the closest shape to what is practically obtained. The radius of the log is taken as 40cm, while the length is 10m. Therefore, utilising the formula of cylinder mentioned in the earlier part of the paper, the volume of the wood is (Figure 3):

$$\text{Volume} = \pi \times 40^2 \times 1000 = 5027200\text{cm}^3$$

If the density of wood is assumed to be $0.8\text{g/cm}^3 = 800\text{kg/m}^3$, then

Mass of sawdust produced = $\frac{\rho V}{1000}$ (from equation (4)).

Also, Q_{prod} = mass of sawdust = $\frac{0.8 \times 5027200}{1000} = 4021.76\text{mg}$.

However, $F_{prod} = \frac{Q}{Q_A}$. By assuming that the approximate flow rate of the enclosure is 120 logs/hr, then $F_{prod} = \frac{2}{1080} = 0.0019$.

Since the total flow rate of enclosure after 9hrs = 1080 logs/hr, volume = $\frac{1080}{90} = 444\text{m}^3$; select 40m^3.

Thus, $C_{inh} = \frac{Q_{prod} \times F_{prod}}{Vc} = \frac{4021.76 \times 0.0019}{40} = 0.1910\text{mg/m}^3$.

In this case study evaluation of ventilation rate, we restrict the situation to no-wind conditions for simplicity of application. However, during rainy seasons, wind is a common occurrence and may affect the prediction. There is lack of systematic research concerning ventilation rates in the Nigerian sawmill environment; data on local ventilation rates for the Nigerian environment is not available at the time of this work, and the best option is relative comparison of ventilation conditions with the other environments and adaptation of suitable data collection in other environments to the Nigerian environment for the purpose of demonstrating the feasibility of the approach proposed here. In a study by Yang and Li (2009), ventilation rates, measured as total air change rate were calculated as 2 – 4per hour (i.e. 2 –4 ACH). The mean i.e. 3 per hour is utilised in this work. Thus, we assume that ventilation rate of a worker is 3 per hour by standards, we let $F_R = 1$.

For T = 1 to 9hrs

Therefore the amount inhaled, $A_{inh} = F_R \times c_{inh} \times Q_{inh} \times T$

Amount inhaled, A_{inh} is calculated for the first entry (S/No. 1) as:

$$A_{inh} = 1 \times 0.502 \times 3 \times 1 \times 60 = 1.506\text{mg per hour}$$

Other values for the amount inhaled are calculated similarly with results shown in Table 1. Note that the inhalation rate in all the nine cases considered is 3 per hour.

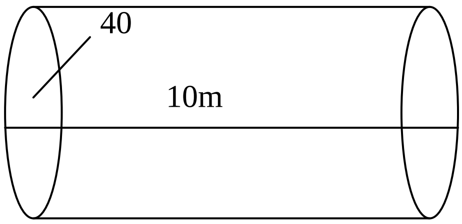

Figure 3. *Illustrative log of wood*

Table 1. *Computation of inhaled volume of saw dust*

S/No.	Time of exposure (min)	Amount (mg)	Inhaled volume m^3
1	1 x 60	1.506	3.012
2	2 x 60	3.012	6.024
3	3 x 60	4.518	9.036
4	4 x 60	6.024	12.048
5	5 x 60	7.530	15.06
6	6 x 60	9.036	18.072
7	7 x 60	10.542	21.084
8	8 x 60	12.048	24.096
9	9 x 60	13.554	27.108

Inhalation rate = 3 per hour

$$A_{inh} = \frac{5.69}{67} \times 1 = 0.08 \text{mg/kg/day} = 31 \text{mg/kg/year}$$

For Dermal Exposure

Assume d = 1%

Therefore $D = \frac{1}{d} = \frac{1}{0.01} = 100$

$F_{prod} = 0.005$

Assuming $Q_{prod} = 4021.76$mg

Let volume of undiffused sawdust be

$$c_{der} = \frac{Q_{prod} \times F_{prod}}{V_{prod} \times D} = \frac{4021.76 \times 0.005}{40 \times 100} = 0.005 \text{mg/m}^3$$

Let us assume that the surface area of the hand is $84 cm^2$. Then, in computation of the surface area of human arms and hands, a value of $200 cm^2$ is used based on the anticipated values that the methods could yield.

Let $T_t = 0.01$cm, then $V_{app} = \text{Area} \times T_t = 0.01 \text{cm} \times 200 \text{cm}^2 = 20 \text{cm}^3$

Therefore $A_{der} = c_{der}$ x Area x T_t = 0.005 x 20 = 0.1mg

Total exposure of the worker = $\frac{A_{inh} + A_{der}}{W}$

Assuming worker's weight is 67kg, then total exposure = $\frac{11.34 + 0.1}{67}$ = 0.17mg/kg/day

From the results obtained, the inhalable air concentration obtained is 1.506 mg/m^3 in air, which is well below the safety standard of 7.14 – 11.91mg/m^3. This implies that the working environment is not a severely hazardous one, and so the sawdust will have just mild effects on the worker. Also, the total amount of sawdust inhaled per day by the worker is 5.69mg, which is less enough; if it were higher the worker could be seriously affected by the respiratory disorders associated with inhaling sawdust. The total amount of sawdust inhaled per body weight of the worker for one year is 31mg/kg/year. For the dermal exposure, the concentration is 0.005mg/cm^3. This means the effect of dermal exposure is very low compared to inhalation exposure.

4. CONCLUSION

From the paper, it is apparent that sawdust is seen as human hazard that can cause adverse effects on the worker upon his exposure in a sawmill. Since we have assumed that the level of exposure depends on the duration of exposure, we then incorporated this into the formula which has aided our understanding that more periods of exposure means accumulated sawdust in the body. As well as that, the amount and concentration of inhalable sawdust in the air is vital in calculating the intake or accumulated sawdust in the lungs. Inhalation exposure is predominantly the deadliest. Adverse effects are greater when there is high exposure. Environmental inhalable sawdust level below 1.0mg/m^3 should be sufficiently safe for the worker. It was also found that exposure to dermal or skin has a negligible effect on the worker in as much as the exposed parts of his body are his arms and hands. In a sawmill, safety measures should be taken such as use of hand gloves, wearing and putting on breathing masks so as to reduce the exposure and hence reduce the risk of being affected by any of the resultant disorders or diseases from the sawdust. In addition to that, the working space should be relatively large to reduce the concentration of inhalable sawdust in the air.

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