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Air Quality Impacts of Smallholder Oil Palm Processing in Nigeria

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ABSTRACT

Air emissions during palm oil processing by smallholders are issues of public health concern demanding urgent intervention by environmentalist. In this study, six smallholder oil palm processing mills were studied in Elele, Nigeria. Air emission parameters (NO_2, NH_3, CO, H_2S, SO_2, VOC), noise and meteorology (wind speed, temperature, relative humidity and pressure) were determined at three distances (10 ft, 25 ft and 50 ft) in both wind ward and lee ward directions from the mills covering boiling and digestion activities. The emissions from biomass were found to be significantly higher than that from fossil diesel, while noise was higher during digestion. The health implications of air emissions were discussed. The study concluded by directing attentions of regulatory agencies to monitor the activities of smallholder oil palm processing to ensure the environmental sustainability of their operations. In summary, evidence during boiling activity revealed that:

- H_2S ranged from <0.01 - 2.400 ppm at 10 ft, <0.01 - 2.067 ppm at 25 ft and <0.01 - 0.833 ppm at 50 ft from the mills in the wind ward direction, and <0.01 - 1.167 ppm at 10 ft, <0.01 - 0.567 ppm at 25 ft and <0.01 - 0.367 ppm at 50ft distance from the mills in lee ward direction and was significantly lower during digestion.
- SPM ranged from 1634 - 7853 μg/m^3 at 10 ft, 657 - 1110 μg/m^3 at 25 ft and 81 - 854 μg/m^3 at 50 ft from the mills in the wind ward direction, and 46 - 236 μg/m^3 at 10 ft, 44 - 120 μg/m^3 at 25 ft and 30 - 58 μg/m^3 at 50 ft from the mills in lee ward direction. SPM was significantly lower during digestion.
- VOC ranged from 67 - 13.933 ppm at 10 ft, 1.033 - 13.133 ppm at 25ft and 0.500 - 9.467 ppm at 50 ft from the mills in the wind ward direction, and 0.300 - 3.200 ppm at 10 ft, 0.133 - 6.733 ppm at 25 ft and 0.100 - 4.773 ppm at 50 ft from the mills in the lee ward direction, but was significantly lower during digestion..

Keywords: Air Emissions; Noise; Oil Palm Processing; Pollutant Gases

1. Introduction

Within the last few years, environmental issues are increasingly becoming relevant in economic activities and public health [1,2] in Nigeria and the rest of the world. Of particular concern is the atmospheric environmental problems, which had previously received scanty attention in Nigeria but have become a subject of increasing National significance, particularly over the last two years [3].

Air pollution is a major threat to human life and most people inhale pollutants while at home or commuting to work irrespective of the mode of transportation [4]. Depending on the dose and the exposure time, these pollutant gases have the potential to cause far reaching adverse health effects in man, but principally affect the respiratory and cardiovascular systems. The World Health Organization (WHO) estimates that about 2.4 million people worldwide (including about 93,700 Nigerians) die each year from causes directly attributable to air pollution [5].

Oil palm (*Elaeis guineensis*) is an indigenous plant to West Africa [6]. It is the most productive oil crop in the world [7-15], accounting for 33% of global vegetable oil production [16]. In Nigeria, over 80% of oil palm cultivation and production are controlled by smallholders [17, 18], who typically harvest semi wild plants and use

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manual processing techniques [19,20].

Unlike large oil palm processing mills, smallholders' operations are done manually and in batches, which depend on biomass fuel during boiling and diesel powered energy input during digestion (**Figures 1** and **2**). The increasing levels of oil palm cultivation and commercial processing in Nigeria thus raises serious environmental concerns due to air emissions generated during local oil palm production.

A hectare of oil palm produces 10 - 35 tonnes of fresh fruit bunch (FFB) per year [21-23]. The cultivation and processing of oil palm is a source of livelihood for many rural dwellers in Nigeria [18]. Oil palms are of multiple values and are crops of high economic importance that are often underscored [24]. The plantations cover a range of 1 - 5 hectares of land and are characterized by mixed cropping to maximize the usage of the land [25].

There are at least eleven steps in the processing of oil palm fruits (**Figure 1**). In smallholder processing operations, all the steps are carried out manually without any external energy input except boiling and digestion. During oil palm processing activities, biomass such as Palm press fiber, empty fruit bunch, palm kernel shells and chaff are mainly used as boiler fuel, generating smoke.

Emissions are also generated from the diesel engine during digestion activity (**Figure 2**), releasing gaseous pollutants such as carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), volatile organic compounds (VOCs) and particulate matter [26,27].

These emissions can be injurious to the environment [2] as well as humans [5,28-30]. H_2S and NH_3 may also be emitted in minute quantities by the combustion of biomass and diesel fuel. The emission from diesel engines depends on the quality of the test fuels used [31,32]. Fossil diesel compositions include 40% paraffin, 35% of aromatic and <10% of olefin [33]. NO_2 is usually generated during combustion at high temperature [34], and its concentration increases with the engine combustion efficiency [35], while most SO_2 from diesel engines is produced by the high-temperature oxidation of the sulfates

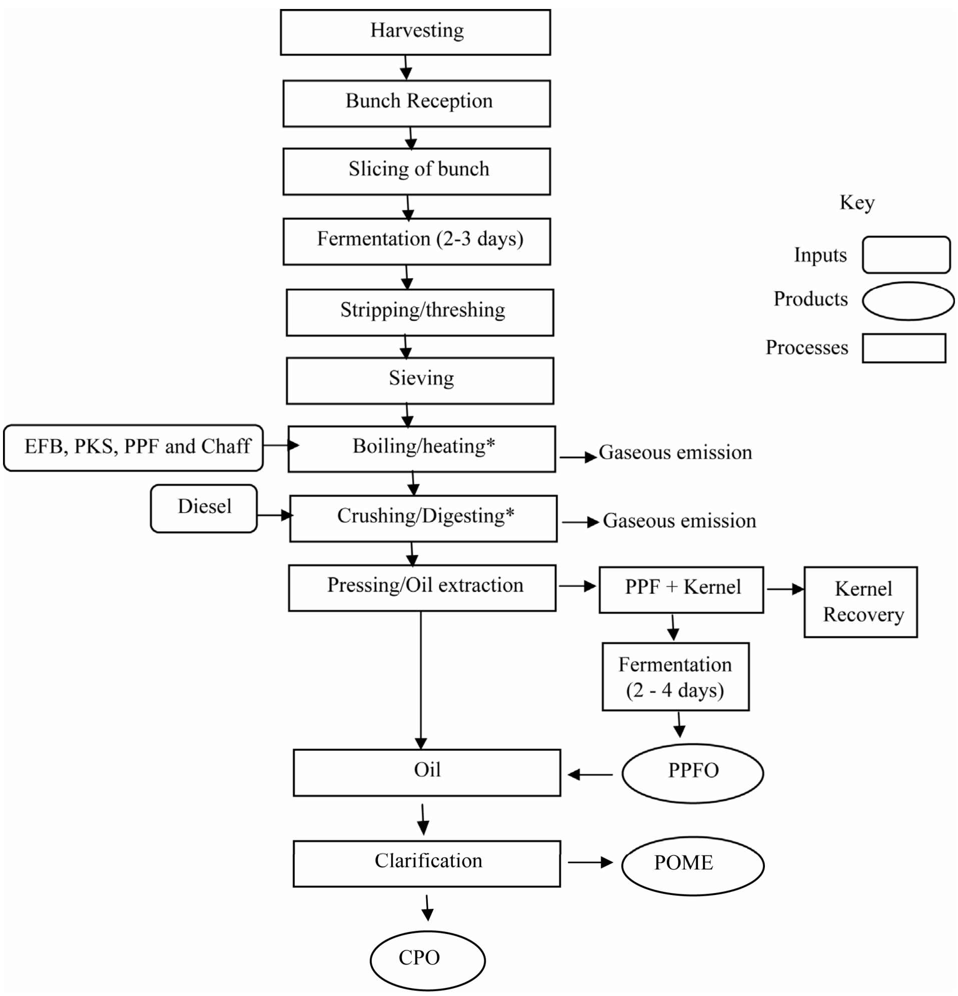

Figure 1. A schematic chart of palm oil processing by smallholders in Nigeria (* = air quality sampling phase; POME = palm oil milling effluents; PPF = palm press fibre; PPFO = palm press fibre oil; CPO = crude palm oil).

Boiling activity

Digestion activity

Figure 2. Emission processes during oil palm processing by smallholders in Nigeria.

in petroleum diesel [34].

After they are emitted into the atmosphere, NO_2 and SO_2 become nitrates and sulfate aerosols respectively that detrimentally affect the environment. SO_2 combined with water vapor in the atmosphere in the presence of a catalyst (NO_2) forms H_2SO_4, and causes acid rain. When these acids are consumed, they cause acidosis in human body, and excess accumulation in the human body can lead to death [36].

This underlies concerns over the environmental impact of the use of these fuels as power sources during palm oil processing by small holders. Emissions of smoke, hydrocarbon etc from burning of biomass (such as wood, crops) and fossil fuels (such as diesel engines and other transportation engines) have received much concern from the general public and environmentalists [28,37-44], and are one of the major environmental problems confronting Nigeria especially the Niger Delta Area, yet information regarding this is very scarce. Apart from data collected by a few individuals and corporate organizations at scattered locations, there is no comprehensive and empirical database on the magnitude of the hazard and its deleterious effects on the ecosystems and the people of the region [30,45].

Noise is generated during all the phases of oil palm processing especially during digesting and oil extraction activity. The meteorological indicators (wind speed, relative humidity, temperature and pressure) of climate are important considerations during oil palm processing. Air humidity conditions, among other factors, may affect human comfort, and could lead to weather-related mortality [46,47] and influences air pollution, which induces respiratory diseases [48]. Although Relative humidity (RH) has an effect on the formation and size of secondary aerosols and therefore on the deposition, it is generally under investigated in urban climate research [49]. This may be related to the fact that humans have difficulties perceiving changes of the relative humidity [50] due to lack of sensory receptors for humidity [51].

In advanced oil palm producing countries, the sector is aware of the pollution associated with the processing activities and they are striving towards quality, environmental conservation through sustainable development and cleaner technology [52]. With the increasing uses of oil palm products, its production increases. So the sector must prepare for the potential challenges associated with it. Environmental pollution is a critical issue that requires attention on a dynamic basis despite the existence of environmental laws and regulations [53].

Air quality studies in Nigeria and particularly the Niger Delta area are still in its infant stage and faced with numerous challenges [30,45]. Apart from the issue of too few air pollution studies, a secondary problem is that they are often independently carried out, and government is not involved in systematic and consistent air quality assessment programmes as is being done in other parts of the world such as that carried out by the Environmental Protection Agency (EPA) in the United States [54]. Hence self regulatory environmental management tools like the ISO 1400 and life cycle assessment (LCA) have been adopted by the palm oil industries where systematic assessment checklists on the whole operation and unit processes and pollution prevention strategies could be effectively formulated and implemented in most advanced oil palm processing countries [52].

The self-regulatory approach by the sector will be essential to protect the environment. Improved air quality could serve as a single health promotion strategy that could be beneficial to all, since everybody commute and breathe air and air pollution is ubiquitous and widespread [4]. Therefore, it becomes pertinent to investigate the air emissions from smallholders' oil palm processing in Nigeria.

2. Materials and Methods

2.1. Field Sampling

Six (6) smallholder oil palm processing mill were visited in Elele, Rivers State, Nigeria from the 13th of April through the 22nd of April 2012. All the oil palm processing mills use similar processes and triplicate samples were collected from each mill specifically during boiling and digestion operations (**Figures 1** and **2**). The environmental components studied include: Air quality, Noise and meteorology.

2.2. Air Quality/Meteorological Measurement

The Air quality/meteorological parameters monitored include total Suspended Particulate, CO, SO_2, NO_2, NH_3, VOCs Noise, Wind speed, Atmospheric temperature, Pressure, and Relative humidity. Parameters such as CO, SO_2, NO_2, NH_3, H_2S, VOCs and noise were measured using *in-situ* pre-calibrated portable air analyzers. Measurement was made at three (3) different distances from the mills (10, 25 and 50 ft) in both the windward and lee-ward directions. The methodologies used for the air quality indicators are discussed below:

2.2.1. Pollutant Gases

Portable environmental air analyzers were employed for the air quality measurement of the pollutants and including: NO_2 (Model number: Z-1400), SO_2 (Model number: Z-1300), NH_3 (Z-800), H_2S (Z-900), CO and VOCs (model ZDL-500). All the above equipment is product of Environmental Sensors Co, Boca Raton, Florida, USA) except VOC which is a product of met-one instrument, USA.

2.2.2. Noise Level

An Extech instrument (China), model 407730 Sound level meter with measuring range of 40 - 130 dB (A), was used to measure the noise level at all the processing mills visited. Measurements were done by directing the probe towards the direction of the prevailing sound and the reading recorded from the digital meter in decibels dB.

2.2.3. Suspended Particulate Matter (SPM)

A Mini-volume air sampler (model: AEROCET 531, Manufactured by Met-one instrument, USA) with a preweighed membrane filter (45 µm) was used to collect particulate matter. With the aid of a pump and a flow-regulating device, air samples were pumped at a flow rate of 5 LPM at ambient conditions. Particle size separation was achieved by impaction and an impactor of 10-micron cut-point was employed. A quartz filter of 47 mm diameter was used for trapping and a sensitive analytical microbalance was used for weighing.

2.2.4. Meteorological Parameters

The Kestrel (model: 4500 NV) manufactured by Nielsen-Kellerman CO, Boothywn, USA meteorological station were used to measure temperature, relative humidity, wind speed and pressure.

2.3. Statistical Analysis

SPSS software version 17 (SPSS Inc., Chicago) was used to carry out the statistical analysis. A one-way analysis of variance was carried out at $\alpha = 0.05$, and Duncan's multiple range test was used to discern the source of the observed differences.

3. Results and Discussion

The results of the air quality analysis during boiling and digestion of oil palm is presented in **Tables 1** and **2** respectively, while noise/meteorology are respectively presented in **Tables 3** and **4**. NO_2 concentration was generally below the equipment detection limits (<0.01 ppm) in most of the mills, though with few exceptions.

During boiling, NO_2 was recorded in few mills; at 10 ft from mill A (0.233 ± 0.033 ppm) and mill D (0.267 ± 0.033 ppm) in the wind ward direction, At mill E, NO_2 was recorded at 25 ft (0.133 ± 0.033 ppm) in the wind ward direction and 10 ft (1.167 ± 0.033 ppm) in the lee ward direction (*i.e.* off wind direction). In mill C, NO_2 was not recorded in the wind ward direction, but only at 50 ft (0.167 ± 0.033 ppm) in the lee ward direction. The may be attributed to sudden change in wind direction as was observed in the particular mill during the study.

During digestion, NO_2 was not recorded at any of the mills in the lee-ward direction but only in mill A, B and C in the wind ward direction. In these mills, NO_2 was consistently higher at the 10 ft distance from the mills and least at 50 ft. Since the permissible limits of NO_2 in Nigeria are 0.04 - 0.06 ppm [55] (**Table 5**), it therefore follows that the limits were exceeded in some of the mills during boiling. However, the levels during the digestion process were within the Nigerian ambient air quality standards.

NO_2 is acidic gas and an important indicator of air pollution as it correlates well with other air pollutant concentrations. NO_2 is emitted during the combustion of fossil diesel and biomass and the variation in the concentration detected in this study is likely to be associated

Table 1. Air quality during boiling activity of oil palm processing in the wind and lee ward directions.

Mill #	Distance (ft)	Emission direction	NO_2, ppm	NH_3, ppm	CO, ppm	H_2S, ppm	SO_2, ppm	SPM, μg/m^3	VOC, ppm
A	10	Wind ward	0.233 ± 0.033c	<0.01a	0.133 ± 0.033ab	0.333 ± 0.033bcde	<0.01a	1634.0 ± 3.0j	13.933 ± 0.291m
	25		<0.01a	<0.01a	0.133 ± 0.033ab	0.433 ± 0.088 bcdef	<0.01a	768 ± 13.0fg	13.133 ± 0.504l
	50		<0.01a	<0.01a	<0.01a	0.567 ± 0.033defg	<0.01a	443.0 ± 8.0e	9.467 ± 0.260k
B	10		<0.01a	0.267 ± 0.033bc	1.867 ± 0.318ef	0.500 ± 0.058cdef	0.167 ± 0.067ab	7853.0 ± 23.0n	4.333 ± 0.203h
	25		<0.01a	<0.01a	0.500 ± 0.058abc	1.800 ± 0.208j	0.167 ± 0.067ab	712.0 ± 21.0f	1.400 ± 0.115e
	50		<0.01a	<0.01a	<0.01a	0.433 ± 0.033bcdef	<0.01a	442.0 ± 10.0e	0.500 ± 0.115ab
C	10		<0.01a	<0.01a	6.467 ± 0.338j	<0.01a	<0.01a	2292.0 ± 30.0k	4.700 ± 0.208hi
	25		<0.01a	<0.01a	5.767 ± 0.145i	<0.01a	<0.01a	657.0 ± 24.0f	3.833 ± 0.260g
	50		<0.01a	<0.01a	0.233 ± 0.067ab	0.167 ± 0.067ab	<0.01a	105.0 ± 5.0abc	2.867 ± 0.033f
D	10		0.267 ± 0.033c	0.300 ± 0.058cd	5.700 ± 0.100i	2.400 ± 0.351k	2.033 ± 0.088e	1089.0 ± 10.0i	1.167 ± 0.088de
	25		<0.01a	0.267 ± 0.033bc	3.067 ± 0.384g	0.367 ± 0.033bcde	<0.01a	684.0 ± 6.0f	2.900 ± 0.058f
	50		<0.01a	<0.01a	0.833 ± 0.088bcd	<0.01a	<0.01a	81.0 ± 2.0abc	1.067 ± 0.088cde
E	10		<0.01a	<0.01a	27.167 ± 0.273m	0.733 ± 0.267fg	0.433 ± 0.285cd	3555.0 ± 99.0l	3.233 ± 0.145f
	25		0.133 ± 0.033b	<0.01a	9.700 ± 0.833k	<0.01a	<0.01a	922.0 ± 15.0h	1.067 ± 0.088cde
	50		<0.01a	<0.01a	7.033 ± 0.639j	<0.01a	<0.01a	170.0 ± 16.0bcd	0.600 ± 0.058abc
F	10		<0.01a	0.667 ± 0.033e	26.700 ± 0.208m	1.100 ± 0.115hi	0.333 ± 0.033bc	4354.0 ± 183.0m	4.800 ± 0.115i
	25		<0.01a	0.433 ± 0.285d	15.233 ± 0.441l	2.067 ± 0.120j	0.633 ± 0.088d	1110.0 ± 26.0i	1.033 ± 0.088cde
	50		<0.01a	<0.01a	9.133 ± 0.167k	0.833 ± 0.033 gh	0.467 ± 0.267cd	854.0 ± 27.0gh	0.533 ± 0.088ab

Continued

	10		<0.01a	<0.01a	<0.01a	<0.01a	<0.01a	236.0 ± 6.0d	3.200 ± 0.173f
A	25		<0.01a	0.167 ± 0.033abc	<0.01a	0.367 ± 0.033bcde	0.167 ± 0.033ab	120.0 ± 1.0abc	6.733 ± 0.176j
	50		<0.01a	<0.01a	<0.01a	0.367 ± 0.033bcde	<0.01a	58.0 ± 2.0abc	4.733 ± 0.088hi
	10		<0.01a	<0.01a	0.133 ± 0.033ab	0.600 ± 0.100efg	<0.01a	68.0 ± 32.0abc	1.067 ± 0.145cde
B	25		<0.01a	<0.01a	<0.01a	0.567 ± 0.033defg	<0.01a	95.0 ± 2.0abc	0.200 ± 0.058a
	50		<0.01a	<0.01a	<0.01a	0.233 ± 0.033abc	<0.01a	36.0 ± 1.0a	0.333 ± 0.033a
	10		<0.01a	0.300 ± 0.058cd	4.267 ± 0.145h	<0.01a	<0.01a	78.0 ± 3.0abc	0.433 ± 0.033ab
C	25		<0.01a	<0.01a	<0.01a	<0.01a	<0.01a	51.0 ± 1.0abc	0.333 ± 0.088a
	50	Lee ward	0.167 ± 0.033b	<0.01a	2.467 ± 0.145fg	<0.01a	<0.01a	39.0 ± 1.0a	0.167 ± 0.067a
	10		<0.01a	<0.01a	1.067 ± 0.088cd	0.567 ± 0.088defg	<0.01a	46.0 ± 2.0ab	0.867 ± 0.033bcd
D	25		<0.01a	<0.01a	0.400 ± 0.058abc	<0.01a	<0.01a	47.0 ± 3.0ab	0.400 ± 0.100ab
	50		<0.01a	<0.01a	<0.01a	<0.01a	<0.01a	40.0 ± 7.0a	0.200 ± 0.058a
	10		1.167 ± 0.088d	0.133 ± 0.033ab	1.267 ± 0.145de	1.167 ± 0.088i	<0.01a	50.0 ± 12.0abc	0.300 ± 0.058a
E	25		<0.01a	<0.01a	<0.01a	0.267 ± 0.067abcd	<0.01a	60.0 ± 4.0abc	0.133 ± 0.033a
	50		<0.01a	<0.01a	<0.01a	0.133 ± 0.033ab	<0.01a	54.0 ± 4.0abc	0.100 ± 0.058a
	10		<0.01a	<0.01a	2.867 ± 0.088g	0.300 ± 058abcde	<0.01a	174.0 ± 12.0cd	0.300 ± 0.058a
F	25		<0.01a	<0.01a	<0.01a	<0.01a	<0.01a	44.0 ± 7.0ab	0.133 ± 0.033a
	50		<0.01a	<0.01a	<0.01a	0.133 ± 0.033ab	<0.01a	30.0 ± 7.0a	0.200 ± 0.058a

Each value is expressed as mean ± standard error (n = 3). Different letters in each column indicate significant differences at $P < 0.05$ according to the Duncan Statistics.

Table 2. Air quality during digestion activity of oil palm processing in the wind and lee ward directions.

Mill #	Distance (ft)	Emission direction	NO_2, ppm	NH_3, ppm	CO, ppm	H_2S, ppm	SO_2, ppm	SPM, µg/m^3	VOC, ppm
A	10	Wind ward	0.167 ± 0.033c	0.167 ± 0.067d	0.700 ± 0.115hi	0.300 ± 0.058b	<0.01	163.0 ± 2.01pq	4.700 ± 0.153i
	25		0.033 ± 0.033ab	0.067 ± 0.033bc	0.300 ± 0.100abcde	0.033 ± 0.033a	<0.01	30.0 ± 6.0abcde	1.100 ± 0.153cde
	50		0.067 ± 0.033b	0.033 ± 0.033ab	0.200 ± 0.058abcd	0.033 ± 0.033a	<0.01	46.0 ± 2.0defghi	0.433 ± 0.067ab
B	10		0.133 ± 0.033c	<0.01a	0.733 ± 0.088hi	0.033 ± 0.033a	<0.01	57.0 ± 3.0fghijk	8.633 ± 0.219m
	25		0.067 ± 0.033b	<0.01a	0.433 ± 0.033defg	<0.01a	<0.01	26.0 ± 3.0abcd	2.100 ± 0.289f
	50		<0.01a	<0.01a	0.167 ± 0.067abcd	0.033 ± 0.033a	<0.01	17.0 ± 7.0a	0.500 ± 0.115ab
C	10		0.233 ± 0.067d	<0.01a	0.733 ± 0.088hi	<0.01a	<0.01	77.0 ± 3.0klmn	10.167 ± 0.410n
	25		0.067 ± 0.033b	<0.01a	0.267 ± 0.088abcde	<0.01a	<0.01	30.0 ± 4.0abcde	2.367 ± 0.273f
	50		<0.01a	<0.01a	0.167 ± 0.067	<0.01a	<0.01	59.0 ± 3.0fghijkl	0.533 ± 0.067ab
D	10		<0.01a	0.100 ± 0.058c	0.700 ± 0.100hi	<0.01a	<0.01	117.0 ± 3.0o	5.767 ± 0.285k
	25		<0.01a	0.067 ± 0.033bc	0.333 ± 0.088abcde	0.033 ± 0.033a	<0.01	84.0 ± 6.0mn	1.567 ± 0.285e
	50		<0.01a	<0.01a	0.267 ± 0.088abcde	<0.01a	<0.01	70.0 ± 4.0ijklm	0.400 ± 0.058ab
E	10		<0.01a	<0.01a	0.867 ± 0.088i	<0.01a	<0.01	78.0 ± 6.0klmn	6.233 ± 0.145l
	25		<0.01a	<0.01a	0.600 ± 0.058fgh	<0.01a	<0.01	34.0 ± 7.0abcdef	1.267 ± 0.273de
	50		<0.01a	<0.01a	0.300 ± 0.100abcde	0.033 ± 0.033a	<0.01	18.0 ± 1.0ab	0.500 ± 0.058ab
F	10		<0.01a	<0.01a	0.633 ± 0.067ghi	<0.01a	<0.01	68.0 ± 9.0hjklm	4.800 ± 0.115ij
	25		<0.01a	<0.01a	0.333 ± 0.088abcde	0.033 ± 0.033a	<0.01	53.0 ± 2.0efghijk	1.067 ± 0.088cd
	50		<0.01a	<0.01a	0.133 ± 0.033abc	<0.01a	<0.01	20.0 ± 5.0abc	0.533 ± 0.088ab

Continued

	10		<0.01a	<0.01a	0.267 ± 0.088abcde	<0.01a	<0.01	28.0 ± 4.0abcde	4.167 ± 0.219h
A	25		<0.01a	<0.01a	0.200 ± 0.058abcd	<0.01a	<0.01	14.0 ± 4.0a	0.367 ± 0.067ab
	50		<0.01a	<0.01a	0.067 ± 0.033a	<0.01a	<0.01	540.0 ± 15.0s	0.367 ± 0.033ab
	10		<0.01a	<0.01a	0.267 ± 0.067abcde	<0.01a	<0.01	51.0 ± 6.0defghij	5.233 ± 0.145j
B	25		<0.01a	<0.01a	0.200 ± 0.058abcd	<0.01a	<0.01	43 ± 2.0bcdefg	0.733 ± 0.088abc
	50		<0.01a	<0.01a	0.200 ± 0.058abcd	<0.01a	<0.01	97.0 ± 25.0no	0.233 ± 0.033a
	10		<0.01a	<0.01a	0.367 ± 0.120bcdef	<0.01a	<0.01	177.0 ± 3.0q	6.500 ± 0.153l
C	25		<0.01a	<0.01a	0.233 ± 0.033abcd	<0.01a	<0.01	28.0 ± 3.0abcde	0.567 ± 0.033ab
	50	Lee ward	<0.01a	<0.01a	0.100 ± 0.058ab	<0.01a	<0.01	53.0 ± 1.0efghijk	0.400 ± 0.058ab
	10		<0.01a	<0.01a	0.400 ± 0.058cdefg	<0.01a	<0.01	63.0 ± 6.0ghijklm	5.133 ± 0.088ij
D	25		<0.01a	<0.01a	0.133 ± 0.033abc	<0.01a	<0.01	43.0 ± 1.0bcdefg	0.467 ± 0.033ab
	50		<0.01a	<0.01a	0.133 ± 0.088abc	<0.01a	<0.01	74.0 ± 2.0jklmn	0.233 ± 0.033a
	10		<0.01a	<0.01a	0.500 ± 0.153efgh	<0.01a	<0.01	82.0 ± 3.0lmn	4.233 ± 0.145h
E	25		<0.01a	<0.01a	0.333 ± 0.088abcde	<0.01a	<0.01	36.0 ± 1.0abcdef	0.800 ± 0.058bcd
	50		<0.01a	<0.01a	0.167 ± 0.033abcd	<0.01a	<0.01	44.0 ± 2.0cdefgh	0.233 ± 0.033a
	10		<0.01a	<0.01a	0.367 ± 0.033bcdef	<0.01a	<0.01	148.0 ± 14.0p	3.500 ± 0.208g
F	25		<0.01a	<0.01a	0.200 ± 0.058abcd	<0.01a	<0.01	15.0 ± 0.0a	0.233 ± 0.033a
	50		<0.01a	<0.01a	0.067 ± 0.033a	<0.01a	<0.01	220.0 ± 5.0r	0.200 ± 0.058a

Each value is expressed as mean ± standard error (n = 3). Different letters in each column indicate significant differences at $P < 0.05$ according to the Duncan Statistics.

Table 3. Noise & meteorology during boiling activity of oil palm processing in the wind and lee ward directions.

Mill #	Distance (ft)	Emission direction	Noise, db	Wind Speed, m/s	Relative Humidity RH, %	Temperature, ˚C	Pressure, hpa
	10		50.70 ± 0.346abc	0.400 ± 0.058bcdefgh	79.967 ± 0.203f	28.03 ± 0.260abcde	1008.50 ± 0.058efg
A	25		52.87 ± 1.093bc	0.267 ± 0.033abcde	84.900 ± 0.346kl	27.43 ± 0.088ab	1008.50 ± 0.058efg
	50		50.73 ± 0.837abc	0.167 ± 0.067ab	83.200 ± 1.159hij	27.53 ± 0.033abc	1008.43 ± 0.033efg
	10		68.90 ± 0.416f	0.133 ± 0.033ab	69.500 ± 0.737cd	34.20 ± 0.513kl	1006.43 ± 0.088abc
B	25		63.50 ± 0.300e	0.233 ± 0.067abcd	68.367 ± 0.145c	32.97 ± 0.393hi	1006.43 ± 0.067abc
	50		52.77 ± 0.285bc	0.200 ± 0.058abc	70.233 ± 0.233d	32.27 ± 0.233gh	1008.27 ± 0.088e
	10		52.70 ± 0.265bc	0.533 ± 0.033efghijk	60.900 ± 0.265a	35.80 ± 0.058m	1006.63 ± 0.088c
C	25		49.27 ± 0.837a	1.567 ± 0.176m	62.433 ± 0.260a	35.40 ± 0.173m	1006.63 ± 0.088c
	50	Wind ward	61.77 ± 0.338de	0.233 ± 0.067abcd	65.600 ± 0.643b	34.03 ± 0.581jkl	1007.27 ± 0.186d
	10		62.93 ± 0.546e	0.767 ± 0.033jk	62.400 ± 0.173a	34.57 ± 0.260l	1006.13 ± 0.145ab
D	25		49.53 ± 0.617ab	0.633 ± 0.328ghijk	64.533 ± 0.176b	33.57 ± 0.186ijk	1006.07 ± 0.088a
	50		49.47 ± 0.437ab	0.733 ± 0.033ijk	64.500 ± 0.265b	33.23 ± 0.240ij	1006.10 ± 0.115a
	10		62.43 ± 0.788de	0.800 ± 0.058k	81.800 ± 0.451gh	29.10 ± 0.493f	1008.63 ± 0.088efg
E	25		61.30 ± 0.493de	0.800 ± 0.058k	83.667 ± 1.081ijk	28.50 ± 0.173def	1008.70 ± 0.000fg
	50		61.53 ± 0.524de	0.167 ± 0.033ab	85.167 ± 0.769klm	28.67 ± 0.133ef	1008.73 ± 0.033g
	10		62.87 ± 0.524e	0.633 ± 0.033ghijk	73.033 ± 0.674e	27.93 ± 0.145abcde	1008.47 ± 0.033efg
F	25		61.87 ± 1.037de	0.700 ± 0.058ijk	86.467 ± 0.784lm	28.30 ± 0.153cdef	1008.63 ± 0.067efg
	50		62.43 ± 0.788de	0.600 ± 0.058ghijk	72.500 ± .351e	27.73 ± 0.088abcd	1008.43 ± 0.033efg
	10		50.50 ± 0.231abc	0.467 ± 0.033cdefghi	80.300 ± 0.153fg	28.17 ± 0.203bcde	1008.33 ± 0.186efg
A	25		52.20 ± 1.050abc	0.133 ± 0.033ab	84.833 ± 0.433jkl	27.27 ± 0.088a	1008.43 ± 0.176efg
	50		50.73 ± 0.736abc	0.167 ± 0.033ab	83.033 ± 1.087hi	27.33 ± 0.167ab	1008.33 ± 0.186efg
	10		66.77 ± 2.046f	0.567 ± 0.067fghijk	70.333 ± 0.186d	33.90 ± 0.458jkl	1006.23 ± 0.088abc
B	25		62.50 ± 0.755de	0.300 ± 0.058abcdef	68.733 ± 0.120cd	33.03 ± 0.145i	1006.27 ± 0.088abc
	50		53.17 ± 0.433c	0.100 ± 0.000a	69.800 ± 0.306cd	32.00 ± 0.058g	1008.37 ± 0.219efg
	10		53.33 ± 0.348c	0.633 ± 0.120ghijk	61.133 ± 0.384a	35.63 ± 0.120m	1006.53 ± 0.067bc
C	25		50.43 ± 0.696abc	0.500 ± 0.058defghij	62.600 ± 0.153a	35.50 ± 0.173m	1006.53 ± 0.120bc
	50	Lee ward	59.23 ± 2.697d	0.267 ± 0.088abcde	65.66 ± 0.6067b	33.93 ± 0.533jkl	1007.33 ± 0.219d
	10		62.30 ± 0.458de	1.200 ± 0.115l	62.533 ± 0.233a	34.60 ± 0.252l	1006.07 ± 0.133a
D	25		52.73 ± 3.000bc	1.367 ± 0.088lm	64.467 ± 0.145b	33.53 ± 0.233ijk	1006.10 ± 0.153a
	50		49.47 ± 0.291ab	0.667 ± 0.088hijk	64.433 ± 0.145b	33.30 ± 0.200ij	1006.10 ± 0.115a
	10		63.43 ± 1.235e	0.667 ± 0.088ghijk	81.767 ± 0.467gh	29.07 ± 0.088f	1008.50 ± 0.173efg
E	25		62.87 ± 1.450e	0.567 ± 0.067fghijk	83.733 ± 1.035ijk	28.57 ± 0.186def	1008.57 ± 0.145efg
	50		60.90 ± 1.153de	0.367 ± 0.067abcdefg	85.133 ± 0.745klm	28.60 ± 0.058ef	1008.30 ± 0.115ef
	10		62.67 ± 0.328e	0.267 ± 0.033abcde	73.033 ± 0.584e	27.93 ± 0.088abcde	1008.60 ± 0.173efg
F	25		61.87 ± 0.801de	0.367 ± 0.067abcdefg	86.600 ± 0.361m	28.40 ± 0.153def	1008.70 ± 0.115fg
	50		63.50 ± 0.351e	0.200 ± 0.058abc	72.2 ± 0.20333e	27.73 ± 0.033abcd	1008.40 ± 0.153efg

Each value is expressed as mean ± standard error (n = 3). Different letters in each column indicate significant differences at $P < 0.05$ according to the Duncan Statistics.

Table 4. Noise & meteorology during digestion activity of oil palm processing in wind and lee ward direction.

Mill #	Distance (ft)	Emission direction	Noise, db	Wind Speed, m/s	RH, %	Temperature, ˚C	Pressure, hpa
A	10	Wind ward	80.70 ± 0.346de	0.533 ± 0.033abcdefg	79.933 ± 0.267h	28.03 ± 0.291abc	1008.67 ± 0.088ef
	25		74.47 ± 0.145c	0.267 ± 0.033abcd	84.733 ± 0.285kl	27.23 ± 0.088a	1008.37 ± 0.120ef
	50		64.07 ± 2.652a	0.167 ± 0.067ab	83.100 ± 1.277ijk	27.43 ± 0.088ab	1008.40 ± 0.153ef
B	10		88.90 ± 0.416f	0.200 ± 0.058abc	69.500 ± 0.666def	33.90 ± 0.252ghij	1006.43 ± 0.145abc
	25		73.50 ± 0.300c	0.167 ± 0.067ab	68.433 ± 0.067de	33.00 ± 0.451f	1006.20 ± 0.058abc
	50		66.10 ± 3.508a	0.200 ± 0.058abc	70.200 ± 0.351f	32.10 ± 0.300e	1008.17 ± 0.088e
C	10		82.70 ± 0.265e	0.533 ± 0.033abcdefg	60.767 ± 0.348a	35.70 ± 0.058l	1006.57 ± 0.033cd
	25		75.93 ± 2.652cd	0.933 ± 0.186g	62.533 ± 0.088b	35.37 ± 0.088kl	1006.50 ± 0.100bc
	50		63.10 ± 1.002a	0.567 ± 0.067abcdefg	65.500 ± 0.529c	34.07 ± 0.570hij	1007.00 ± 0.306d
D	10		83.60 ± 1.206e	0.867 ± 0.233fg	62.467 ± 0.088b	34.67 ± 0.273jk	1006.07 ± 0.448abc
	25		76.20 ± 2.757cd	0.633 ± 0.328bcdefg	64.600 ± 0.100c	33.57 ± 0.088fghi	1005.90 ± 0.100a
	50		66.80 ± 2.425ab	0.667 ± 0.033cdefg	64.400 ± 0.058c	33.17 ± 0.203fg	1006.00 ± 0.115ab
E	10		82.43 ± 0.788e	0.633 ± 0.067bcdefg	81.800 ± 0.252ij	29.03 ± 0.481d	1008.37 ± 0.176ef
	25		74.63 ± 2.948c	0.800 ± 0.058efg	83.367 ± 0.974jkl	28.47 ± 0.033cd	1008.50 ± 0.153ef
	50		64.53 ± 1.369a	0.600 ± 0.200abcdefg	84.967 ± 0.902lm	28.57 ± 0.033cd	1008.70 ± 0.115ef
F	10		82.87 ± 0.524e	0.767 ± 0.067efg	73.100 ± 0.709g	27.87 ± 0.267abc	1008.27 ± 0.088ef
	25		71.87 ± 1.037c	0.700 ± 0.058defg	86.467 ± 0.612m	28.53 ± 0.120cd	1008.60 ± 0.115ef
	50		64.43 ± 1.178a	0.733 ± 0.088defg	72.300 ± 0.300g	27.40 ± 0.058ab	1008.27 ± 0.088ef
A	10	Lee ward	80.57 ± 0.418de	0.533 ± 0.033abcdefg	79.900 ± 0.361h	28.13 ± 0.120bc	1008.73 ± 0.033f
	25		74.20 ± 0.058c	0.267 ± 0.033abcd	84.500 ± 0.351kl	27.53 ± 0.145ab	1008.57 ± 0.145ef
	50		63.97 ± 2.674a	0.133 ± 0.033a	83.067 ± 1.161ijk	27.30 ± 0.153ab	1008.63 ± 0.033ef
B	10		88.90 ± 0.351f	0.267 ± 0.033	69.267 ± 0.498def	34.03 ± 0.348hij	1006.43 ± 0.145abc
	25		73.60 ± 0.252c	0.333 ± 0.145abcd	68.200 ± 0.058d	33.10 ± 0.404fg	1006.20 ± 0.058abc
	50		62.90 ± 0.351a	0.400 ± 0.100abcde	69.967 ± 0.338ef	31.90 ± 0.252e	1008.17 ± 0.088e
C	10		82.53 ± 0.285e	0.533 ± 0.033abcdefg	60.667 ± 0.318a	35.40 ± 0.100kl	1006.30 ± 0.058abc
	25		75.57 ± 2.696cd	0.933 ± 0.186g	62.233 ± 0.088ab	35.60 ± 0.058l	1006.50 ± 0.100bc
	50		63.33 ± 0.984a	0.667 ± 0.260cdefg	65.267 ± 0.521c	34.30 ± 0.557ij	1006.30 ± 0.058abc
D	10		83.53 ± 1.284e	0.700 ± 0.100defg	62.400 ± 0.058b	34.67 ± 0.273jk	1006.07 ± 0.448abc
	25		75.90 ± 2.762cd	0.700 ± 0.265defg	64.300 ± 0.058c	33.43 ± 0.145fgh	1006.23 ± 0.120abc
	50		66.67 ± 2.153ab	0.667 ± 0.033cdefg	64.200 ± 0.058c	33.27 ± 0.491fgh	1006.17 ± 0.088abc
E	10		82.33 ± 0.636e	0.700 ± 0.265defg	81.633 ± 0.240i	29.10 ± 0.321d	1008.37 ± 0.176ef
	25		74.67 ± 2.928c	0.667 ± 0.033cdefg	83.267 ± 1.017ijkl	28.70 ± 0.153cd	1008.50 ± 0.153ef
	50		64.33 ± 1.485	0.600 ± 0.200abcdefg	84.967 ± 0.865lm	28.53 ± 0.120cd	1008.70 ± 0.115ef
F	10		82.50 ± 0.300e	0.667 ± 0.033cdefg	72.933 ± 0.644g	27.90 ± 0.252abc	1008.37 ± 0.145ef
	25		71.60 ± 0.945bc	0.400 ± 0.208abcdef	86.433 ± 0.521m	28.60 ± 0.173cd	1008.60 ± 0.115ef
	50		64.13 ± 1.214a	0.467 ± 0.186abcdefg	71.967 ± 0.384g	27.17 ± 0.088a	1008.60 ± 0.208ef

Each value is expressed as mean ± standard error (n = 3). Different letters in each column indicate significant differences at $P < 0.05$ according to the Duncan Statistics.

Table 5. Air quality, noise and meteorology recommendation guideline.

Parameter	NigerianAmbient Air Quality Standard [55]	
	Time of average	Limits
Ambient Temperature °C	*	30°C
Noise (dB)A	*	90
NO_2 (ppm)	Daily average of hourly values (range)	0.04 ppm - 0.06 ppm (75.0 μg/m^3 - 113 μg/m^3)
NH_3 (ppm)	*	*
SO_2 (ppm)	Daily average of hourly values 1 hour	0.01 ppm (26 μg/m^3) 0.1 ppm (260 μg/m^3)
H_2S (ppm)	*	*
CO (ppm)	Daily average of hourly values 8-hourly average	10 ppm (11.4 μg/m^3) 20 ppm (22.8 μg/m^3)
VOC (ppm)	*	*
SPM (μg/m^3)	Daily average of hourly values 1 hour	250 μg/m^3 600 μg/m^3

*No stated limit.

with combustion temperature [56]. NO_2 emission from digestion activity is dependent upon the speed of the engine and the load [57]. NO_2 poses important environmental and public health concerns as it contributes to greenhouse gas levels and high levels of NO_2 is associated with increased risk of respiratory diseases and contributes to heart, lung, liver and kidney diseases [30].

Ammonia was not generally detected in most of the mills during boiling and digestion activities, except in few instances. During boiling, ammonia was highest at 10 ft (<0.01 - 0.667 ppm), followed by 25 ft (<0.01 - 0.267 ppm) and not detected at 50 ft in the wind ward direction. Whereas in the lee ward direction ammonia was only recorded (0.133 - 0.300 ppm) at 10 ft distance from only 3 mills (A, C and E), and was not detected at other distances in the mills. Ammonia was generally absent during digestion both in the lee ward and wind ward directions except in mill A, B, C where it was recorded in the wind ward direction at 10 ft (0.133 - 0.233 ppm), 25 ft (0.033 - 0.067 ppm) and 50 ft (<0.01 - 0.067 ppm). Though, Nigeria does not have permissible limits for ammonia, the difference between the lee ward and wind ward concentration can be used to assess the impact. The result show that the concentration of ammonia released during boiling activity is significantly higher ($P < 0.05$) than that released during the digestion activity indicating that biomass fuel contribute higher levels of ammonia to the atmosphere than fossil fuel.

CO was detected at all the mills, during boiling and digestion activities at the 3 distances (10 ft, 25 ft and 50 ft) from the mills in both wind ward and lee ward directions. During boiling, CO was 0.133 - 27. 167 ppm at 10 10 ft, 0.133 - 15.233 ppm at 25 ft and <0.01 - 9.133 ppm at 50 ft in the wind ward direction, whereas in the lee ward direction it was significantly lower ($P < 0.05$) ranging from <0.01 - 4.267 ppm at 10 ft, <0.01 - 0.567 ppm at 25 ft and <0.01 - 2.467 ppm at 50 ft from the mills. The higher emission generated at 25 ft could be associated to the addition of more biomass/boiler fuel during measurement. During digestion, CO ranged from 0.633 - 0.867 ppm at 10 ft, 0.267 - 0.600 ppm at 25 ft and 0.133 - 0.300 ppm at 50 ft from the mils in the wind ward direction, whereas in the lee ward direction it ranged from 0.267 - 0.500 ppm at 10 ft, 0.133 - 0.333 ppm at 25 ft and 0.067 - 0.200 ppm at 50 ft from the mills. CO was significantly higher during boiling than during digestion.

In all cases CO was highest in the 10 ft distance and least at 50 ft distance from the mills, the values recorded in the wind ward direction is significantly higher than those recorded in the lee ward direction. CO was higher than the Nigerian permissible limit of 10 ppm (daily hourly average) and 20 ppm (8-hourly average) [55] (**Table 5**) only during boiling activities thus indicating superiority of fossil fuel and higher combustion efficiency of the diesel generator compared to direct biomass burning. Typically, CO gas is produced by the incomplete combustion of carbonaceous materials or fossil fuels-gas, oil, coal and wood. The variation in the emission of CO is associated with the load, because the higher the load, the richer fuel mixture is burned, and thus produces more CO [56]. CO is of health concern as it inhibits the bloods ability to carry oxygen to vital organs such as the heart and brain.

The severity of the health effects is dose dependent. Typical sickness symptoms include headache, dizziness and nausea. CO is associated with reduced exercise tolerance, particularly in people with coronary artery disease, because of the formation of carboxyhaemoglobin [29,58].

During boiling activity, H_2S ranged from <0.01 - 2.400 ppm at 10 ft, <0.01 - 2.067 ppm at 25 ft and <0.01 - 0.833 ppm at 50 ft from the mills in the wind ward direction, whereas at the lee ward direction it was <0.01 - 1.167 ppm at 10 ft, <0.01 - 0.567 ppm at 25 ft and <0.01 - 0.367 ppm at 50 ft distance from the mills. During digestion activity, H_2S concentration ranged from <0.01 - 0.300 ppm at 10 ft, <0.01 - 0.033 ppm at 25 ft and <0.01 - 0.033 ppm at 50 ft in the wind ward direction, and was not detected in any of the mills in the lee ward direction.

Nigeria has no permissible limit for H_2S, hence impact shall be established based on the differences between the values recorded in the wind ward direction relative to the lee ward direction. The pattern of variation in H_2S is similar to that observed in other air quality parameters, being highest during boiling activity than digestion and values recorded at the wind ward direction was significantly higher than the lee ward direction. In most of the mills, H_2S was lowest at 50 ft from the mills *i.e.* the concentration decreases with increasing distance from the mills. These results also show the superiority of fossil fuel combustion over biomass in the processing of oil palm.

SO_2 was recorded only in few instances during boiling activity only. During boiling, SO_2 ranged from <0.01 - 2.033 ppm at 10 ft, <0.01 - 0.633 ppm at 25 ft and <0.01 - 0.467 ppm at 50 ft from the mills in the wind ward direction, whereas at the lee ward direction, it was <0.01 ppm in all the mills except at 25 ft from mill A where a value of 0.167 ± 0.033 ppm was recorded. SO_2 was not detected at any distance during digestion activity. SO_2 exceeded the permissible limits of 0.01 - 0.10 ppm [55] (**Table 5**) during boiling activity, thus indicating the superiority of fossil fuel combustion over direct biomass combustion. Basically SO_2 are produced by the combustion of fossil fuels containing sulphur.

SPM was very high especially during boiling activity ranging from 1634 - 7853 μg/m^3 at 10 ft, 657 - 1110 μg/m^3 at 25 ft and 81 - 854 μg/m^3 at 50 ft from the mills in the wind ward direction, whereas in the lee ward direction, it was 46 - 236 μg/m^3 at 10 ft, 44 - 120 μg/m^3 at 25 ft and 30 - 58 μg/m^3 at 50 ft from the mills.

During digestion, SPM ranged from 57 - 167 μg/m^3 at 10 ft, 14 - 84 μg/m^3 at 25 ft and 17 - 70 μg/m^3 at 50ft from the mills in the wind ward direction, whereas in the lee ward direction it was 28 - 177 μg/m^3 at 10 ft, 14 - 43 μg/m^3 at 25 ft and 44 - 540 μg/m^3 at 50ft from the mills. SPM was significantly higher ($P > 0.05$) during boiling activity than during digestion.

The highest value of SPM was recorded at 10ft distance to the mills in the wind ward direction, which decreased at increasing distance to the mills. The results also indicated that lower SPM was generated during digestion using diesel fossil fuel, again, showing that the diesel fossil fuel emit lesser SPM than wood fuels. While the SPM recorded during digestion activity were within the permissible limits of 250 - 600 μg/m^3 [55] (**Table 5**) but SPM release during the boiling activity was significantly higher than this limit. The mass, size, number and particle composition are affected by combustion processes, condensation, adsorption, coagulation, agglomeration and collision of hydrocarbon in the engine exhaust [59,60] Diesel exhaust (DE) is a major contributor to combustion derived particulate matter air pollution. The particulate matter generated is in the form of carbon black, soot and fly ash which are major components of smoke and are often within 10 μm size range [45].

SPM exposure affects the lungs and heart, although the patho-physiological mechanism is not fully understood, due to the chemically heterogeneous nature of SPM [29]. Generally, however, it has been associated with decrease in lung function in children and adults, premature deaths from respiratory and cardiac causes and increased hospital admissions for asthma-like conditions [28]. Ossai *et al.* [61] and Efe [36] asserted that high rate of particulate matter causes respiratory diseases such as emphysema, pneumonia, bronchitis, asthma and respiratory tuberculosis. Also it can lead to eyes, teeth, and bones damage, increased susceptibility to disease and other stress-related environmental hazards, and reduces the reproduction potential in some species [62-65]. Other diseases associated with particulate matter include acute vascular dysfunction, increased thrombus formation pulmonary edema, etc. [45].

During boiling activity VOC ranged from 1.167 - 13.933 ppm at 10 ft, 1.033 - 13.133 ppm at 25 ft and 0.500 - 9.467 ppm at 50 ft from the mills in the wind ward direction, while at the lee ward direction it was 0.300 - 3.200 ppm at 10 ft, 0.133 - 6.733 ppm at 25 ft and 0.100 - 4.773 ppm at 50 ft from the mills. During digestion, VOC ranged from 4.700 - 10.167 ppm at 10 ft and 1.067 - 2.367 ppm at 25 ft and 0.400 - 0.533 ppm at 50 ft from the mills in the wind ward direction, whereas in the lee ward direction, it was 3.500 - 6.500 ppm at 10 ft, 0.233 - 0.800 ppm at 25 ft and 0.200 - 0.400 ppm at 50 ft from the mills. VOC was significantly higher during boiling activity than digestion, and in the wind ward than lee ward direction. The concentration of VOC was highest at 10 ft to the mills and decreased with increasing distance to the mills. The low molecular weight organic fractions are highly volatile and with short atmospheric life-time.

Although the Nigerian ambient air quality standards does not specify any limit for VOC, health effects from these chemical compounds depend on the type, level and length of exposure. Short term exposure is likely cause of sensory irritation, particularly of the eyes, nose and throat [50] while long term exposure may lead to liver, kidney damage and cancer. However, VOCs could be affected byrelative humidity recorded in some mills [66,67].

During boiling activity noise ranged from 50.70 - 68.90 dB at 10 ft, 49.27 - 63.50 dB at 25 ft and 49.47 - 62.43 dB at 50 ft from the mills in the wind ward direction, whereas in the lee ward direction it was 50.50 - 66.77 dB at 10 ft, 50.43 - 62.87 dB at 25 ft and 49.47 - 63.50 dB at 50 ft from the mills. During digestion, noise ranged from 80.70 - 88.90 dB at 10 ft, 71.87 - 76.20 dB at 25 ft and 63.10 - 66.80 dB at 50 ft from the mills in the wind ward direction, whereas in the lee ward direction, it was 80.57 - 88.90 dB at 10 ft, 71.60 - 75.90 dB at 25 ft and 62.90 - 66.67 dB at 50 ft from the mills.

There were no significant difference ($P > 0.05$) in the noise levels recorded at the wind ward and lee ward direction, indicating that the intensity of noise is unaffected by wind direction. From these results it will appear that noise pollution is not of serious concern during local processing of palm oil. Unlike in the other parameters, noise do not follow wind direction and was significantly higher ($P < 0.05$) during digestion than during boiling. This is expected because the Lister engine generates noise during digestion. Noise level was below the FEPA stipulated limit of 90 dB [55] (**Table 5**) during boiling and digestion activities.

During boiling activity, atmospheric temperature ranged from 27.93˚C - 35.80˚C at 10 ft, 27.43˚C - 35.40˚C at 25 ft and 27.53˚C - 34.03˚C at 50 ft from the mills in the wind ward direction, whereas it was 27.93˚C - 35.63˚C at 10 ft, 27.27˚C - 35.50˚C at 25 ft and 27.33˚C - 35.93˚C at 50 ft from the mills in the lee ward direction. During digestion, temperature ranged from 27.87˚C - 35.70˚C at 10 ft, 27.23˚C - 35.37˚C at 25 ft and 27.40˚C - 34.07˚C at 50 ft to the mills in the wind ward direction, whereas in the lee ward direction it was 27.93˚C - 35.40˚C at 10 ft, 27.53˚C - 35.60˚C at 25 ft and 27.17˚C - 34.30˚C at 50 ft from the mills. The temperature was found to be greater that the permissible limit of 30˚C [55] (**Table 5**). Though temperature decreased at increasing distances from the mills, there were no significant differences between the values recorded at the wind ward and lee ward wind directions and between boiling and digestion processing activities.

The wind speed ranged from 0.100 - 1.567 m/s during boiling and 0.133 - 0.933 m/s during digestion, which is classified as light air in the Beaufort scale. The wind speed and direction affected the concentration of air quality parameters but did not influence noise and temperature significantly. Relative humidity ranged from 62.40% - 86.60% during boiling and 60.79% - 86.43% during digestion, while pressure ranged from 1006.07 - 1008.73 hpa during boiling and 1006.00 - 1008.87 hpa during digestion. It does appear that relative humidity and pressure has no differential effects on the air quality parameters. The high values obtained in some mills and the distance from the processing activity may be attributed to reduced cloud cover and the influence of moisture laden tropical maritime air mass. However, RH appears to enhance particle deposition [67,68].

The occasional increase in the emission from the longer distance as compared to short distance in some of the parameters is associated to the fueling of boiler fuel during measurement while the digestion activity was enhanced by the loading rate. Other factors are changes in wind speed and direction. This basically influenced both direction (lee and wind ward) measurements.

4. Conclusion

This study investigated the air quality during palm oil processing by smallholders in Nigeria. The air quality parameters (NO_2, NH_3, CO, H_2S, SO_2, VOC, SPM) during boiling activity were found to exceed the threshold limits. Emissions during digestion activity were however within the threshold limits. Therefore, emissions during the boiling process could pose serious environmental and public health concern which portends negative implications for environmental sustainability. We recommend the use of improved burners that could emit fewer pollutants. Also, government should develop environmental quality guidelines for smallholder oil palm processing activities to ensure environmental sustainability of their operations.

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