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ABSTRACT: Mosquito coils are commonly burnt in indoor environments to drive away mosquitoes which are vectors for malaria parasites. The levels of carbon monoxide (CO) emitted and human health implications during smoldering of 5 different brands of mosquito coils commonly used in Nigeria were investigated in 4 microenvironments of different sizes. The experiments were done by taking a scenario of a sleeping arrangement and the farthest distance between the coil burning and an arbitrary bed position in 4 different bedrooms of different sizes in poor ventilation condition of closed doors and windows. With monitoring device, ALTAIR 5X portable gas analyzer, at the position of the bed, measurements were taking at 2 minutes interval from start to the end of burning of each coil. The emission profile was determined by making concentration-time plots of CO emission to determine its levels from the burning of each brand of the mosquito coils in each microenvironment. From the emission profile, coils A, C, and D showed that CO levels exceeded Nigeria's Federal Ministry of Environment (FMEnv) and the World Health Organization (WHO) statutory limit of 9.0 ppm for indoor environments in each of the microenvironments between 3 and 7 hours after the burning commenced. It was concluded that the CO concentrations from smoldering mosquito coils is a function of the size of the microenvironment in which it is used. It was recommended that the size of a microenvironment be determined for consumption of a mosquito coil before it is released into the market.

KEYWORDS: Mosquito coils, burning, emission, carbon monoxide, levels of exposure, Nigeria

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Introduction

Humans mostly spend 90% of their lives indoors which can lead to exposure to indoor air pollutants. According to the World Health Organization[1] and Midouhas et al[2], air inside our homes can be 5 times more toxic than air outside our homes depending on pollutant sources and nature of ventilation of the indoor environment. Mosquito repellents are used in most homes to drive away mosquitoes which are the principal vectors for malaria parasite. The use of these coils is a significant cause of indoor air pollution. Recent WHO figures estimated nearly 7 million annual premature deaths; 1 in 8 of the total deaths was due to exposure to air pollution.[3-7] This incredible figure makes air pollution one of the biggest health threats in the world. Most of the deaths from this conservative estimate come from combustion of biomass fuels and smoldering mosquito coils where half of the world's population in the developing countries rely on these crude fuels for multiple needs.[8,9] The disease burden in developing countries is relatively high, and malaria-a vector-borne disease is no exception.

Approximately 2 billion people worldwide are using mosquito coils.[10] These coils are usually made up active ingredients that could be any or a combination of pyrethroids such as metofluthrin, d-allethrin d-trans allethrin, and prallethrin and the percentage of the active ingredients usually ranged between 0.10% and 2.0%.[10] These substances are low-toxicity insecticides. Research conducted in Malaysia has shown that a harm done to lungs by 1 mosquito coil is equivalent to the damage done by burning 75 to 137 cigarettes.[11] Volatile organic compounds (VOCs), including carcinogens and suspected carcinogens, are evidenced by coil smoke.[11] Extended use of mosquito coils raises the incidence of asthma and excessive wheezing.[10]

In Nigeria, mosquito coils have been the major mosquito repellents because they are not expensive and can easily be purchased in the neighborhood. Mosquito coils contain insecticides that slowly vaporize into the air to provide mosquito protection to prevent malaria. Some of the toxic contaminants that may result from the burning of mosquito coils and related incense-like items are carbon monoxide (CO), VOCs, sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matters (PM).[12-14] These pollutants in mosquito coils pose threats to human health. This research focused on the investigation of indoor levels of CO from brands of smoldering mosquito coils used in Nigeria. It also evaluated the potential implication with inhalation of CO from the identified smoldering mosquito coils in the selected microenvironments.

Materials and Methods

Mosquito coils

Five different brands of smoldering mosquito coils A, B, C, D, and E were used in this study. The mosquito coils were purchased from retail outlets in Lagos, a key commercial center with huge population and a former capital territory of Nigeria.

Table 1. General information of the identified mosquito coils.

ID NO	COUNTRY OF ORIGIN	MASS PER COIL (G)	COLORS	ACTIVE INGREDIENTS	SHAPE
A	China	12.3	Black	D-Allethrin	Spiral
B	Nigeria	13.6	Black	Meperfluthrin	Spiral
C	Nigeria	14.8	Black	Pyrethroid (D-allethrin)	Spiral
D	Nigeria	10.2	Ash	Plantfiber, meperfluthrin	Spiral
E	Nigeria	10.0	Ash	Pyrethroid (permethrin)	Spiral

Table 2. Average temperature and relative humidity in the micro-environments at poor ventilated condition.

MICRO-ENVIRONMENT ID	MICRO-ENVIRONMENT SIZE (M^3)	TEMPERATURE (°C)	RELATIVE HUMIDITY (%)
MC1	67.69	28.67 ± 0.78	71.75 ± 4.31
MC2	20.17	28.53 ± 0.78	69.78 ± 5.44
MC3	18.48	28.34 ± 0.78	70.66 ± 4.30
MC4	17.00	28.31 ± 0.78	71.53 ± 5.11

The identification and selection of the mosquito coils were based on the extent of popularity of the product in the local market and the frequency of use. Information on the different brands of mosquito coils selected for investigation is summarized in Table 1.

Description of the micro-environments (MC)

The monitoring of the levels of exposure to the CO emissions was undertaken in 4 selected micro-environments (bedrooms) of different sizes. There dimensions of the 4 micro-environments were 5.90 m × 3.85 m × 2.98 m (MC1), 3.98 m × 1.70 m × 2.98 m (MC2), 3.50 m × 2.20 m × 2.40 m (MC3), and 3.98 m × 1.70 m × 2.98 m (MC4). Each room was fixed with a door of dimensions 197 cm × 76 cm and 2 windows, each of dimensions 87 cm × 65 cm. The doors and windows were closed without mosquito nets. Experiments were conducted under poor ventilated conditions (with windows closed), a scenario in which mosquito coils are used in Nigeria. The average temperature and relative humidity in the experimental rooms are indicated in Table 2.

Determination of the profiles of exposure to CO emission from the identified smoldering mosquito coils in the selected micro-environments

In order to determine the concentrations of CO emitted from the smoldering mosquito coil, a mosquito coil within the coil packet was lit on the metal stand and placed at the extreme end of a bed position in each microenvironment with monitor on the bed as shown in Figure 1. Each experimental set up was started at 7 pm each day, the traditional time in Nigeria. At the start of each experiment, the doors and windows were closed to simulate a typical scenario of mosquito coil use in Nigeria. Measurements were taken immediately after the coil was lit at 2 minutes interval and recorded values taken for 6 to 8 hours depending on how long the coils burnt. Measurements continued until the CO concentration decayed to zero in each of the microenvironments. Beyond this period, the doors and windows were opened to allow natural ventilation to dilute and disperse all potential emissions in the room. Before the commencement of monitoring, natural ventilation was allowed for few hours to avoid fugitive CO emission. The zero-point accuracy of the sensors was reached by carrying out the fresh air calibration each time prior to measurement inside the experimental microenvironments. ALTAIR 5X portable gas analyzer (Plate 1) which was obtained from Ribble Enviro Ltd, UK was used for the monitoring program. It is a small, light, and easy to use device which makes it very ideal for field monitoring in areas where conventional monitoring requirements are somehow restricted. The device provides optimal functionality even under harsh conditions. This monitor measures up to 3 gases simultaneously and for the purpose of this study only CO was required. The device has a high resolution of 0.1 ppm for CO with a very short response time of 15 seconds.

Results and Discussion

For each brand of mosquito coil and microenvironment (MC), the consumption time (minutes) was plotted against concentration of CO (ppm) to portray the profiles of exposure during the burning of the selected smoldering mosquito coils. The profiles for the 5 brands of mosquito coils in MCI, MC2, MC3, and MC4 are shown in Figures 2 to 5 respectively.

It was observed that the profile of CO emission (ppm) from burning of mosquito coils in each of the selected MC gradually

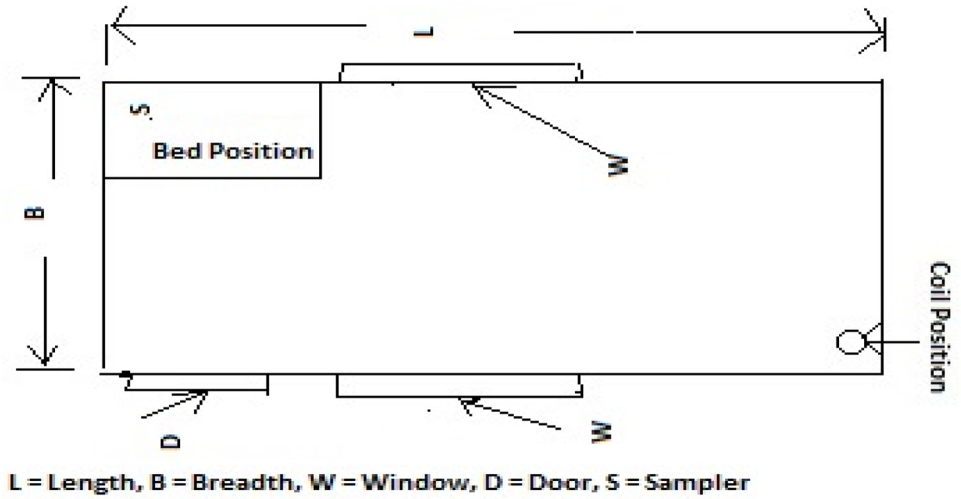

Figure 1. Diagram depicting the positions of the bed, doors, windows, coil, and the monitor.

Plate 1. ALTAIR 5X portable gas analyzer.

increased from 0.00 ppm to an elevated value and remained dynamically constant throughout the burning and then decreased gradually after burning to 0.00 ppm. From the results, the CO profile is dependent on the brand of mosquito coil and the size of the micro-environments (MCs).

For MC1, Figure 2 shows the profile of CO emission from the burning of brand A. It took 58 minutes before the monitoring device, ALTAIR 5X portable gas analyzer, began to sense the emission. The coil burned for another 52 minutes before reaching the statutory limit of 9.00 ppm of CO emission. The burning continued to give values dynamically in the range of 10.00 to 13.00 ppm above the statutory limits for 290 minutes (4.833 hours) and then stopped. Then, the CO concentration in MC1 began to decay sharply and dynamically to 0.00 ppm taking 42 minutes. It took 30 minutes before the gas monitor began to sense the CO emission at 1.00 ppm from brand B. Statutory limit was not reached throughout the burning process but burnt dynamically giving values in the range of 1.00 to 2.00 ppm for 524 minutes (8.23 hours) and then stopped. The decay of the emission went for 38 minutes. The gas monitor started sensing CO emission after 10 minutes of burning of brand C. The CO concentration rose to 8.00 ppm in 80 minutes and remained between 7.00 and 8.00 ppm for 302 minutes. It reached 9.00 ppm of statutory limit after 396 minutes (6.60 hours) of burning. The CO concentration rose to 11.00 ppm and fluctuated between 11.00 and 10 ppm, above the statutory limit for point source emission, for 120 minutes after which the burning stopped. The emission decayed in 78 minutes after burning. For coil D, CO emission started being sensed by the gas monitor as early as 6 minutes after burning at the value of 1.00 ppm and this reading was constant for 142 minutes. It then rose to 2.00 ppm after 150 minutes of burning and gravitated between 2 and 1.00 ppm dynamically for another 210 minutes. Readings at 3.00 ppm began after 362 minutes of burning and was constant for another 120 minutes after which the burning stopped. Statutory limit was not reached throughout the burning. Then the decay of the CO emission went stepwise as shown in the figure for 34 minutes. As early as 10 minutes after burning of coil E, the monitor began to sense CO emission as it rose from 1.00 to 10.00 ppm, above the limit of 9.00 ppm, in 156 minutes. The readings fluctuated between 10.00 and 11.00 ppm for another 242 minutes and the burning stopped. It took the accumulated CO in MC1 76 minutes to decay to zero.

In MC2 of size 3.98 m × 1.70 m × 2.98 m, Figure 3 shows the profile of CO emission from burning of coil A. The gas monitor began sensing the CO emission after 42 minutes of burning at the value of 1.00 ppm. The CO concentration rose from 1.00 to 11.00 ppm above the limit of 9.00 ppm in another

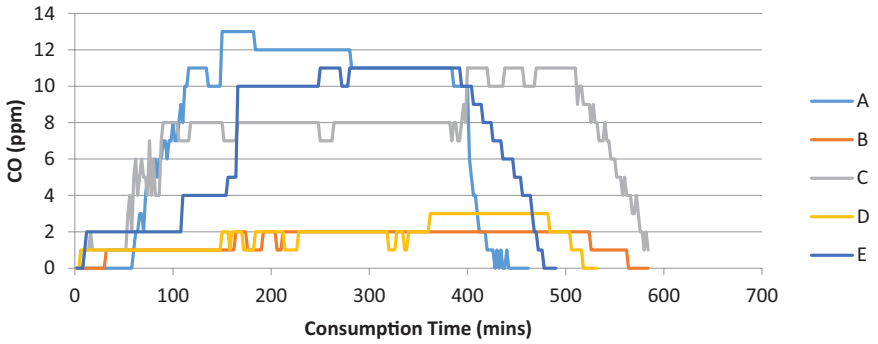

Figure 2. Emission profiles of CO from Brands of Mosquito coils in MC1.

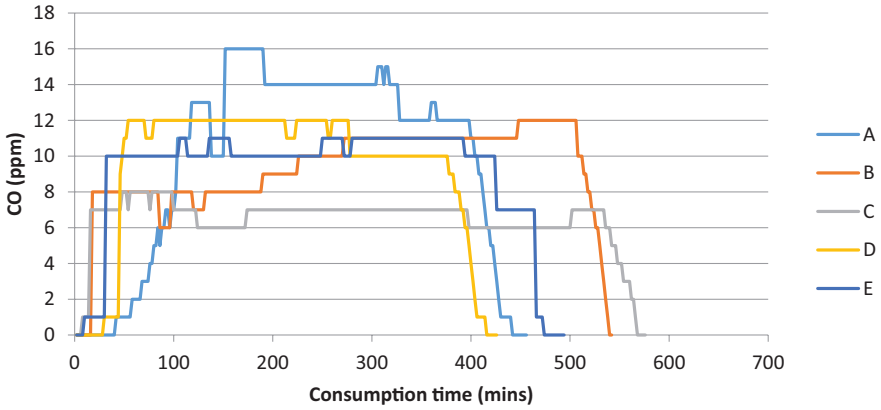

Figure 3. Emission profiles of CO from brands of mosquito coils in MC2.

62 minutes. The CO concentration stayed above 9.00 ppm between 11.00 and 16.00 ppm for 302 minutes. The decay of the emission in MC2 lasted for 34 minutes. The profile of CO emission resulting from the burning of coil B with the gas monitor sensing the CO emission after 18 minutes of burning at 8.0 ppm is also shown in Figure 3. The CO concentration rose to 10.00vppm above the limit in another 206 minutes and gravitated between 10 and 12.00 ppm for 286 minutes and stopped. The decay of the CO concentration lasted for 26 minutes. For coil C, the gas monitor began to sense CO emission after 8 minutes at 1.00 ppm. The concentration rose to 7.00 ppm in 16 minutes and remained dynamically between 6 and 8.00 ppm for 524 minutes before burning stopped. The time of dilution to 0.00 ppm was 24 minutes. CO emission resulting from the burning of coil D with the gas monitor sensing the CO emission after 30 minutes at 1.00 ppm is also shown Figure 3. The concentration rose to 10.00 ppm above WHO standard of 9.00 ppm in another 18 minutes and remained above the limit dynamically between 10 and 12.00 ppm for 328 minutes before burning stopped. The time of dilution to 0.00 ppm was 40 minutes. For coil E, the gas monitor began to sense CO emission after 10 minutes at 1.00 ppm. The concentration rose to 10.00 ppm in another 22 minutes and remained dynamically between 10 and 11.00 ppm for 392 minutes before burning stopped. The time of dilution to 0.00 ppm was 50 minutes.

In MC3 of size 3.50 m × 2.20 m × 2.40 m, Figure 4 shows the profiles of CO emission from burning of all brands of coil. For brand A, the gas monitor began sensing the CO emission after 20 minutes of burning at the value of 1.00 ppm. The CO concentration rose to 10.00 ppm above the limit of 9.00 ppm in another 66 minutes. The CO concentration gravitated and stayed above 9.00 ppm between 10.00 and 19.00 ppm for 306 minutes till the end of burning. The decay of the emission in MC3 lasted for 52 minutes. For brand B, the sensing of CO emission began after 20 minutes at 1.00 ppm. The concentration rose to 3.00 ppm in another 82 minutes and remained dynamically between 3 and 2.00 ppm for 392 minutes which were below the 9.00 ppm limit before burning stopped. The time of dilution to 0.00 ppm was 24 minutes. The sensing of CO emission resulting from the burning of coil C began after 10 minutes at 1.00 ppm. The concentration rose to 13.00 ppm above WHO standard of 9.00 ppm after 156 minutes and remained above the limit dynamically between 13 and 12.00 ppm for 124 minutes before burning stopped. The time of dilution to 0.00 ppm was 22 minutes. For CO emission resulting from the burning of coil D, sensing commenced after 32 minutes at 1.00 ppm. The concentration rose to 10.00 ppm above WHO standard of 9.00 ppm in another 20 minutes and remained above the limit dynamically between 10 and 12.00 ppm for 464 minutes before burning stopped. The time of dilution to 0.00 ppm was 30 minutes. The sensing of CO

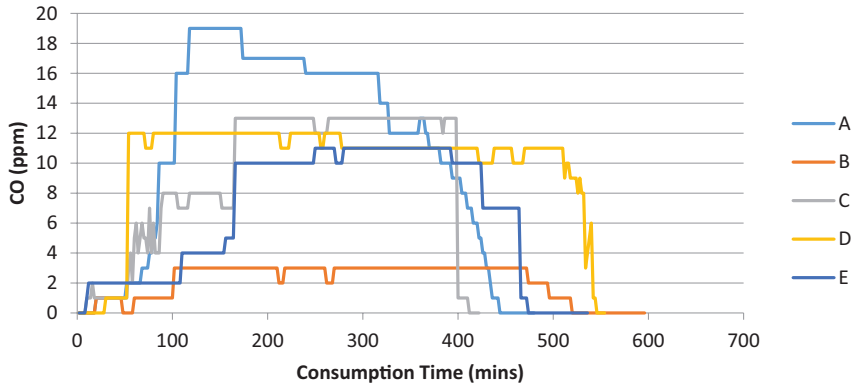

Figure 4. Emission profiles of CO from brands of mosquito coils in MC3.

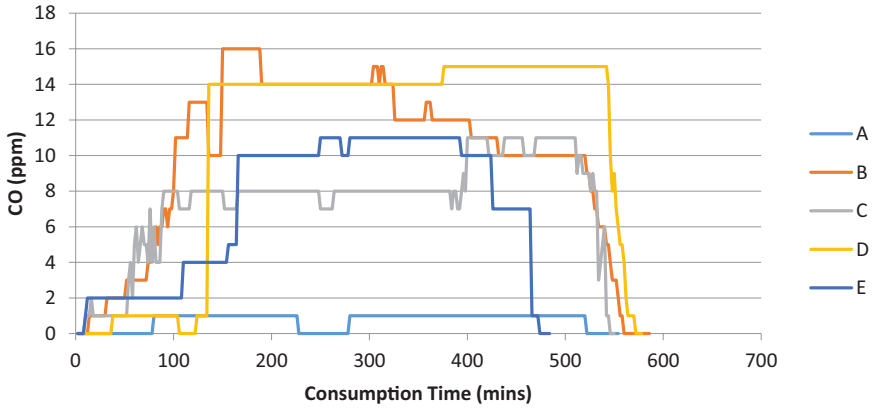

Figure 5. Emission profiles of CO from brands of mosquito coils in MC4.

emission resulting from the burning of coil E began after 10 minutes at 1.00 ppm. The concentration rose to 10.00 ppm above WHO standard of 9.00 ppm in another 156 minutes and remained above the limit dynamically between 10 and 11.00 ppm for 258 minutes before burning stopped. The time of dilution to 0.00 ppm was 50 minutes.

In MC4 of size 3.98 m × 1.70 m × 2.98 m, CO emission profiles emanating from the burning of coil brands are shown in Figure 5. For brand A, the gas monitor began to sense the CO emission after 78 minutes at 1.00 ppm. The concentration remained below the limit dynamically between 1.00 and 0.00 ppm for 442 minutes before burning stopped. The time of dilution to 0.00 ppm was 2 minutes. CO emission resulting from the burning of coil B began to be sensed after 14 minutes at 1.00 ppm. The concentration rose to 11.00 ppm above WHO standard of 9.00 ppm in another 88 minutes and remained above the limit dynamically between 10 and 14.00 ppm for 418 minutes before burning stopped. The time of dilution to 0.00 ppm was 40 minutes. CO emission resulting from the burning of coil C was sensed after 10 minutes at 1.00 ppm. The concentration rose to 11.00 ppm above WHO standard of 9.00 ppm in another 390 minutes and remained above the limit dynamically between 10 and 11.00 ppm for 116 minutes before burning stopped. The time of dilution to 0.00 ppm was 30 minutes. From coil D, sensing of CO emission commenced after 38 minutes at 1.00 ppm. The concentration rose to 14.00 ppm above WHO standard of 9.00 ppm in another 98 minutes and remained above the limit dynamically between 14 and 15.00 ppm for 408 minutes before burning stopped. The time of dilution to 0.00 ppm was 28 minutes. Sensing of CO emission resulting from the burning of coil E began after 110 minutes at 1.00 ppm. The concentration rose to 10.00 ppm above WHO standard of 9.00 ppm in another 156 minutes and remained above the limit dynamically between 10 and 14.00 ppm for 258 minutes before burning stopped. The time of dilution to 0.00 ppm was 48 minutes.

Similar to what was observed by Hogarh et al[12], the present study also observed the presence of CO during the characterization of emissions from smoldering mosquito coils. However, while Hogarh et al[12] reported that the observed level of CO did not pose any health risk based on life time exposure hazard index, the levels obtained in this study are above the permissible limit set by WHO. Bear et al[15] obtained the levels of CO from different brands of smoldering mosquito coils that ranged between 16 and 19 ppm which exceeded that permissible limit of 9.0 ppm set by WHO for indoor environment. They concluded that these CO levels could pose human health risk. Results from the present study agree with this assertion as peak CO levels as high as 13.0, 16.0, 19.0 ppm were obtained from brand A in the MC1, MC2, and MC3 environments respectively. This observation is not

limited to brand A as coil D also showed peak CO emission of 15.0 ppm in MC4. Liu et al[16], focused on emission of pollutants such polycyclic aromatic hydrocarbons, particulate matter, aldehydes and ketones from smoldering mosquito coils, and reported levels that could pose human health risk.

Conclusion

Carbon monoxide (CO) emissions from indoor burning of 5 brands of mosquito coils commonly used in Nigeria have been investigated in 4 micro environments of different sizes. Results showed that the use of mosquito coils could create an unsafe indoor concentration of CO. The smaller the room size, the more the observed CO concentration and consequently the toxicity of the emitted CO to human health. When using the smoldering mosquito coils, it is advisable to use them in spacious rooms that are well ventilated. The coils should be lit far away from the bed position. The inclusion of a label on which micro environment size suitable for the use of mosquito coils should be made compulsory for manufacturers. The individual profiles of CO emission from burning of mosquito coils should be determined before the release into circulations.

Data Availability Statement

The data in Table 1 were generated from the specifications written on the cartons of the identified mosquito coils which are publicly available. Table 2 was generated from the experiments. Figure 1 is the picture of ALTAIR 5X portable gas analyzer used and it is publicly available. Figures 2 to 5 were generated from the experiments.

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