Cigarette Equivalents: Simple Wick Kerosene Lamp
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1.0 Background

Cigarette Equivalents and Considerations

Exposure to a pollutant is often expressed in terms of cigarette equivalents (CE) to provide a reader with an intuitive and familiar frame of reference. Think of it as a first approximation or rough comparison. While useful for giving meaning to non-intuitive measures, it should be interpreted (and wielded) with caution for a few reasons. First, these are rough approximations that use many simplifying assumptions. Although nice for generating hypotheses and exploring influential factors, these approximations do not substitute for actual field measurements. Second, while we can estimate that the quantity of pollutant (e.g. Particles or particulate matter, abbreviated PM) inhaled from a source (e.g. Lamp) is equivalent to smoking some number of cigarettes, we can’t necessarily assume that the health risk will scale in the same way. As discussed below, particles are a “marker” to represent smoke and just one of hundreds of constituents of smoke. We choose PM because it has historically been among the most reliable pollutant indicators for health risk (see section below), but in theory, a cigarette equivalent could be made from many of the compounds emitted from a kerosene lamp. Relative to what we get from using PM, our resulting cigarette equivalent value could be much bigger (e.g. Black carbon) or much smaller (e.g. Carbon monoxide).

A quick note: what is described in this document is distinct from “toxic equivalency” - which is essentially a sum of the toxic potency of pollutants from the source that a person is exposed to.

Since we don’t actually have a good characterization of the emitted pollutants from a kerosene lamp (besides PM), it’s difficult to imagine anyone estimating. I mention this because it’s what the WHO document states. It may also be a simple misuse of the terminology, which happens often.

Why particulate matter?

Smoke from combustion often contains hundreds of health damaging (and non-damaging) compounds (1, 2). For practical purposes we often use a handful of pollutants to serve as “indicators” or “markers” of the smoke mixture. Fine particulate matter, abbreviated as “PM”, is perhaps the most common marker and has been associated with increased risk of many diseases and negative health outcomes. I highlight the word “associated” because PM itself is used as a representative of the smoke mixture, and not necessarily the single agent causing the ill-health.

In the context of health, PM is most often categorized into two size categories (but others exist) based on the diameter of the particles: fine/respirable/PM2.5 (diameter cutoff at less than 2.5 microns = 0.0000025 meters), coarse/inhalable/PM10 (diameter cutoff at less than 10 microns).
As the synonyms would suggest, most PM2.5 can be respired and deposited in the deep lung, while PM10 (which by definition contains PM2.5) can also deposit in the upper lung or throat. The vast majority of particles generated from combustion sources are typically below PM2.5. When measuring particles in the air (e.g. Room air, air inhaled by a person), we express our measurements in concentration units of particle mass per volume of air sampled. For example, an average of 1.5 mgPM2.5/m3 means that there was an average of 1.5 mg of PM2.5 in each cubic meter of air sampled.

2.0 Assumptions and Method

The question we want to answer is: what is the daily exposure to a pollutant from a kerosene lamp, expressed in cigarette equivalents. We will use PM2.5 as an example, but the equivalents could be estimated with any of the other pollutants. We have to make a few assumptions about the source and the cigarette: Cigarette: How much PM2.5 is inhaled by a person (mainstream) from smoking a cigarette? Based on published estimates, the PM2.5 dose from a single cigarette will typically vary from 10-25 mgPM2.5/cigarette, averaging out at around 12 mgPM2.5/cigarette (3, 4). Thus, for PM2.5, a cigarette equivalent will be assumed to be 12 mgPM2.5.

Lamp Source: Estimating for an indoor source requires three steps: (1) Estimate the pollutant concentration in the room, (2) estimate the inhaled dose, (3) convert the dose to cigarette equivalents.

(1) Pollutant Concentration in the Room: We can approach this two ways: rely on previously measured values of the PM concentrations in a room during the use of a lamp OR make our own estimates of air concentrations based on how fast PM2.5 is emitted from these lamps (termed the emission rate or ER). The former is nice because they are actual measurements. The latter is nice because it allows us to estimate the exposure under different assumptions and conditions which would alter the pollutant concentration (e.g. How big is the room, how ventilated is the room).

The Equation 1 is a simplified way of roughly estimating the concentration of a pollutant in a room resulting from a constantly emitting pollutant source. It is appropriate to use if the time a person spends exposed is much greater than 15-20 minutes (given our assumption about the room ventilation rate being about 8/hr):

\[
 Conc_{\text{steady-state}}\left(\frac{mgPM_{2.5}}{m^3}\right) = \frac{ER_{PM2.5}\left(\frac{mgPM_{2.5}}{time}\right)}{\alpha\left(\frac{1}{time}\right) \times V\left(m^3\right)}
\]

Alternatively, we can apply Eq. 2, which does not require meeting the minimum exposure time for Eq. 1.
Eq 2.

\[
\text{Conc}_{\text{TWA}} \left( \frac{\text{mg}}{\text{m}^3} \right) = \frac{\text{ER}_{\text{PM2.5}}}{\alpha \times V \times (T_2 - T_1)} \times \left[ T_2 + \frac{V}{\alpha \times V} \exp(-\alpha \times T_2) - T_1 - \frac{V}{\alpha \times V} \exp(-\alpha \times T_1) \right]
\]

T1 and T2 represent the time points for starting and stopping exposure relative to the moment that the lamp is lit. If a person is exposed from the start, the value for T1 is just a very small number (e.g. 0.0001 hrs). For short exposures, Eq. 2 will yield a smaller result than Equation 1, but as the exposure time gets longer (> 20-30 min) the results will become nearly the same.

Next, to roughly calculate dose, we just need the pollutant concentration from Step 1, the breathing rate of a person, and the hours of exposure. We can also apply a deposition fraction to represent the amount of particles that actually deposit. Then, we simply multiply together (units are expressed in parentheses):

\[
\text{SimpleDose} \left( \frac{\text{mgPM2.5}}{\text{Day}} \right) = \text{Conc} \left( \frac{\text{mgPM2.5}}{\text{m}^3} \right) \times \text{BreathingRate} \left( \frac{\text{m}^3}{\text{hr}} \right) \times \text{ExpHrs} \left( \frac{\text{hr}}{\text{day}} \right) \times \text{DepFract}
\]

Since we have defined a cigarette equivalent to be 12 mgPM2.5 (12 mgPM2.5/cigarette equivalent), we just divide our lamp dose estimate by 12 to convert the lamp dose to CEPM.

\[
\text{CE}_{\text{PM}} \left( \frac{\text{CigEquiv}}{\text{Day}} \right) = \frac{\text{SimpleDose} \left( \frac{\text{mgPM2.5}}{\text{Day}} \right)}{12 \frac{\text{mgPM2.5}}{\text{CE}}}
\]

3.0 Estimates

**Method 1: Using Emission Rates**

**Method 1: Step 1** To estimate the concentration of PM in the room we assume that one lamp is burned inside a well-mixed room that is 40 m³ in volume and has an hourly air exchange rate (number of times the air in the room is replaced by ventilation per hour) of 8 per hr. Assuming a smaller room or air exchange rate would increase the concentration of pollution (more cig. Equivalents) - think about burning a lamp in a living room with all the windows open vs using it in a closet with no windows. Emission rates of a simple wick lamp are approximately 0.7 gPM2.5/hr (5, 6). Using our room assumptions and emission rates we can estimate that the PM2.5 concentration in the room at steady state will be approximately 2-3 mgPM2.5/m³. This is a rough approximation but gets us in the ballpark.
Method 1: Step 2 We assume that a teenager or adult spends 3-4 hrs/day exposed to the lamp and that they have a breathing rate of approximately 15 m³/day or 0.625 m³/hour (7). Combining with our result from Step 1, we come to a simple dose estimate in the range of 4-8 mgPM2.5/day from the lamp.

Expressed in terms of cigarette equivalents, this is around 0.5 cigarettes per day.

Method 2: From Literature

Using mock experiments in a representative Kenyan roadside Kiosk, Apple et al. (2010) estimated that kiosk concentration would be around 0.4-0.5 mgPM2.5/day during use of a simple wick lamp, and a vendor would be exposed to approximately 1.5 to 1.8 mgPM2.5/day. This is equivalent to about 1/6 of a cigarette per day.

Using a mock village hut, Schare and Smith (1995) estimated indoor particle concentrations ranging from 6.7 to 21 mg/m³ (8). Applying our assumptions of breathing rate and exposure times from Method 1, we get a cigarette equivalent estimate between 1-4 cigarette equivalents per day.

4.0 Conclusions

Using a basic approximation, we estimate that the quantity of inhaled PM2.5 from the use of a single simple wick kerosene lamp operated for 3-4 hours per day is roughly equivalent to 0.2-4 cigarettes equivalents per day, with a “most likely” estimate around 0.5. The estimate would be slightly smaller for children who have lower respiration rates than applied rate of 15-18 cubic meters per day.

For comparison to other sources of PM2.5, Figure 1 from Pope et al. (2009) plots the risk of various heart diseases versus the dose per day of PM2.5 resulting from three sources of exposure (from left to right on graph): outdoor air pollution, secondhand smoke, and cigarette smoking.

The estimate for lamp dose falls approximately between secondhand smoke and the very bottom of smoking. Solid fuel cooking would fall more directly in the middle (empty space) and the lower region of smokers (9). This figure is simply to illustrate the two extremes of PM2.5 exposure in a population and estimates should not be used to infer actual health risk.
Figure 1. Adapted from Smith and Peel (2009) and Pope et al. (2009)
References


Cigarette equivalent estimates were provided by Nicholas Lam at the University of California, Berkeley. For more information please contact Kat Harrison, Director of Research & Impact at SolarAid on kat.harrison@solar-aid.org