Potential Health Impacts of Particles and Gases Emitted by Wildfires

Jeff Wagner and Wenhao Chen
Environmental Health Laboratory, California Department of Public Health, Richmond, CA

US EPA ORD Clean Air Spaces web summit, June 12, 2019, RTP, NC

Disclaimer: This presentation is intended to provide scientific background information on wildfire smoke and ash measurement; it does not represent direct guidance.

All microscope images from current CDPH/EHL research, unless cited otherwise.
Presentation outline

1. Introduction / public health goals
2. Wildfire smoke and ash chemicals
3. Indoor air cleaner performance
4. Current EHL wildfire measurements
5. Conclusions
Introduction

• Need for improved smoke & ash chemical exposure assessment:
  • Unique chemical components of smoke/ash may impact human health differently than non-wildfire PM
  • AQI also may not be protective enough if any of these are significant:
    • PM$_{10-2.5}$ (ash/metals) too large for PM$_{2.5}$ AQI
    • ultrafine particles too small for PM$_{2.5}$ sensors
    • toxic gases not included in most AQI calculations
Introduction

- **Known wildfire health effects:**
  - **Wildland firefighters:** *respiratory, neurological* symptoms after fires; *longer-term lung function* decrements (Austin, 2008; Domitrovich et al, 2017)
  - **General public:** acute exposure -> hospital admissions for *respiratory, cardiovascular, and cerebrovascular* events (Wettstein et al, 2018)
  - **General PM\textsubscript{2.5}** (particulate matter <2.5 um) and PM\textsubscript{10-2.5} (coarse PM):
    - acute and chronic *inflammation* -> respiratory and cardiopulmonary effects
    - increased *mortality, hospitalization, and asthma* emergency room visits, especially susceptible individuals (Pope and Dockery, 2006; Peters et al, 2011; Lee et al, 2006; Adar, 2014)
    - PM\textsubscript{2.5} and PM\textsubscript{10} regs / AQI based on chronic (annual) or daily (24-hr) health study findings

- **Unknowns:**
  - **<24-hr smoke exposure**
    - Cal/OSHA regulations = 8-hour “nuisance dust” limits ~ 1,000x public health limits
    - 60 min general PM\textsubscript{2.5} exposures associated with increased cardiac arrhythmia (He et al, 2011)
  - **Chronic exposure to smoke chemicals** (Domitrovich et al, 2017)
Introduction

• **CDPH EHL** is characterizing physical / chemical forms of wildfire emissions to inform decision makers to best monitor and reduce public exposure

  • **Smoke and ash measurements** collected during 2017-18 wildfires, including home filters

  • **Public data** and **combustion / aerosol science** review

  • **Identification of knowledge gaps**

  • ID of other wildfire pollutants **beyond PM2.5**

  • **Trainings** for local and state agencies
Wildfire particle type #1: Organic carbon

- Amorphous, organic carbon (OC) particles and spherical “tar balls”, 50-500 nm
  (Adachi and Buseck 2011; Posfai et al., 2003; China et al 2013; Hand et al., 2005; Wagner et al, 2012)
  - Dominant in low temperature, smoldering biomass emissions (wildfires, cookstoves, crop burning)
  - Water soluble, enriched in potassium and sulfur
  - Hydrocarbons include ~5% polycyclic aromatic hydrocarbons (PAH) = known or probable carcinogens / toxics [e.g., Benzo [a] pyrene, Benzo (b + k) fluoranthene] (CARB, 2003; Robinson et al, 2011)
  - Ultrafine OC PM from peat wildfires causes significantly decreased cardiac function (Kim et al 2014)
Wildfire particle type #2: Soot

- Health effects associated with soot particles, above and beyond general PM
  - Short term health effects stronger for diesel “black carbon” than general PM (Schwartz et al, 2005; Grahame, 2009)
  - Diesel soot toxicity theorized to be influenced by PAH coating (Steiner et al, 2016)
- Short term soot exposure (5 min – 24 hr) associated with increased heart rate variability (Adar et al, 2007)
- Relatively minor component of biomass fires (5-10%)
- Major component of burned diesel (S), unleaded and leaded gasoline (Pb and Br), and burning tires (Murr 2009; Clague et al., 1999; Li et al, 2004; Adachi and Buseck, 2008)

Chain agglomerates of 20-60 nm, graphitic, elemental carbon particles, with sorbed organic carbon and inorganics (China et al, 2013; Adachi and Buseck, 2011)
Wildfire particle type #3: Ash

• Remnants of burned plants and building materials, mostly > 2.5 um on a mass basis
  • Plant ash: C, K, Cl, Ca, Si, S, and Na (Kurkela et al, 1997; Li et al, 2004; Wagner et al 2012; Biolex, 2009; Pitman, 2006)

• Inhalation of PM$_{10-2.5}$ causes inflammation; can contain metals, especially if emitted from fires in urban areas (Adar et al, 2014)

• Metals in soil and ash from 2007-9 CA wildfires (Wolf et al, 2010)
  • elevated levels of chromium(VI) [toxic, carcinogenic], arsenic, lead, and antimony
  • highly caustic (pH = 10-12)

• Fly ash = spherical, inorganic PM from coal or high temperature biomass burning (Lind et al, 2000)

2017 SF Bay Area wildfire smoke

Wagner et al, 2003

2017 SF Bay Area wildfire smoke

Wagner et al, 2012

Wagner, 2009
Other wildfire particle type: Petroleum and plastic emissions

- **Burning oil**: \( \text{PM}_{10-2.5} \) or larger OC (Miller and Linak, 1996; Huffman et al., 2000; Lighty et al., 2000; Marrone et al 1983; Allouis et al 2003; Lippman et al, 2006)
  - Coke particles with vanadium and nickel (and Zn and Fe)
  - \( \text{PM}_{10} \) containing Ni (and possibly V) causes increased heart rate variability above that caused by normal \( \text{PM}_{10} \)

- **Burning synthetic materials** produced >10x more \( \text{PM}_{2.5} \) than wood; mostly UFP <150 nm (Fabian et al, 2010)
  - styrene (e.g. disposable plastic glasses and dishes, insulation, appliances, electronics, toys, tires, vehicles)
  - vinyl polymers (e.g. PVC pipe, wiring, siding, resin chairs and tables)
  - Arsenic (sometimes >STEL), cobalt, chromium, lead, phosphorous, mercury, and PAHs.
  - Wood product PM increased with fraction of adhesives
Other wildfire particle type: Post-fire building material PM

- Exposed building materials and friable dust are potential sources of carcinogens and toxics
  - Carcinogenic asbestos
  - Irritant fiberglass dust
  - Toxic metals (lead, chromium, arsenic, copper, mercury) from partially burned batteries, paint, electronics, solder, pipes, treated wood

Asbestos released by heat, formerly encapsulated in brakes (De Vita et al, 2012)

Crumbled paint with micrometer sized lead (bright spots) (Wall et al 2002)

Crumbled furniture foam with brominated flame retardant (Wagner et al 2013)
Effect of particle size on inhalability & transport

In some cases, shifting meteorology can also force entire PM$_{2.5}$ plume to the ground and into breathing zone

Hinds, 1982

PM$_{2.5}$ more likely to deposit in nose and throat

PM$_{10-2.5}$ more likely to deposit in lungs & trachea

Ash = PM$_{10-2.5}$

Soot, tar balls = PM$_{2.5}$

PM$_{2.5}$ plume more likely to stay aloft

Ash = PM$_{2.5}$ will settle to ground at faster rate

Harnly et al, 2012

Wagner, 2009

Wagner et al, 2012

Hinds, 1982
Wildfire Gas Emissions

- Wildfire smoke gas hazard types, measured close to fire (adapted from Fabian et al, 2010)

<table>
<thead>
<tr>
<th>Type of gas-phase hazard</th>
<th>Gas species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphyxiants</td>
<td>CO, CO₂, H₂S</td>
</tr>
<tr>
<td>Irritants and allergens</td>
<td>NH₃, HCl, NOₓ, phenol, SO₂, isocyanates</td>
</tr>
<tr>
<td>Carcinogens</td>
<td>benzene, styrene, formaldehyde</td>
</tr>
</tbody>
</table>

- Gas chemical concern groups based on Hazard Ratios = EF / TLV (adapted from Austin, 2008):

<table>
<thead>
<tr>
<th>Hazard ratio groups</th>
<th>Gas species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>CO, formaldehyde, acrolein, NOₓ</td>
</tr>
<tr>
<td>Group 2 (One order of magnitude less)</td>
<td>benzene, CO₂, [PAH], NH₃, furfural</td>
</tr>
<tr>
<td>Group 3 (Two orders of magnitude less)</td>
<td>acetaldehyde, 1,3-butadiene, methane, methanol, styrene, acetonitrile, propionaldehyde, toluene, methyl bromide, methylethylketone, acetone, methyl chloride, xylenes, phenol, tetrahydrofuran, methyl iodide, mercury</td>
</tr>
</tbody>
</table>

- Hazardous gas emissions from associated burning products and building materials (Fabian et al, 2010)
  - Polystyrene plastics: benzene, phenols, and styrene
  - Vinyl compounds: acid gases (HCl and HCN) and benzene
  - Wood products: formaldehyde, formic acid, HCN, and phenols
  - Roofing materials: SO₂ and H₂S.
# Wildfire PM and Gas Measurement Options

<table>
<thead>
<tr>
<th>Wildfire emissions measurement type</th>
<th>Measured quantity</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Samplers (need to take back to lab to analyze)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filters or impactors</td>
<td>PM(<em>{2.5}), PM(</em>{10-2.5}), PM(_{10}) (Gravimetric mass); PAHs</td>
<td>True mass; size fractions; PAHs by GC/MS</td>
</tr>
<tr>
<td>Electron microscopy / Impactors, thermophoretic samplers; passive samplers*</td>
<td>PM, PM(<em>{10-2.5}), PM(</em>{10}) (Size, shape, chemistry)</td>
<td>Detailed particle ID; size distributions; passive samplers are low cost, but need longer sampling times</td>
</tr>
<tr>
<td>Active or passive* sorbent tubes, badges, or gas canisters</td>
<td>VOCs, NOx</td>
<td>GC/MS, HPLC</td>
</tr>
<tr>
<td><strong>Continuous monitors (best time resolution)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laser photometers; low cost optical sensors*</td>
<td>PM(<em>{2.5}), PM(</em>{10-2.5}), PM(_{10}) (Light scattering)</td>
<td>Can be very sensitive to particle size and composition</td>
</tr>
<tr>
<td>Beta attenuation</td>
<td>PM(_{1.0}) (Beta radiation absorption)</td>
<td>Signal can be noisy at high time resolution</td>
</tr>
<tr>
<td>Aethalometers</td>
<td>BC or UVPM (Light absorption at specific wavelengths)</td>
<td>Correlation with specific pollutants not well known</td>
</tr>
<tr>
<td>Aerodynamic/electrodynamic/condensation counters</td>
<td>UFP (Single particle light scattering)</td>
<td>Size distributions possible in some models</td>
</tr>
<tr>
<td>Photo-ionization detectors</td>
<td>VOCs (total HCs)</td>
<td>Standard size lamp in multi-gas detectors ineffective</td>
</tr>
<tr>
<td>Long path UV spectrometers</td>
<td>VOCs, NOx</td>
<td>Interferences for toluene and styrene</td>
</tr>
<tr>
<td>Electrochemical/MOx sensors and colorimetric tubes</td>
<td>VOCs, CO, NOx</td>
<td>some interference from other compounds, qualitative</td>
</tr>
<tr>
<td>Portable GC-MS</td>
<td>VOCs</td>
<td>High detection limit</td>
</tr>
<tr>
<td>OP-FTIR</td>
<td>VOCs, NOx, CO</td>
<td>Difficult to implement successfully in the field</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
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</tr>
<tr>
<td>Satellite/remote sensing*</td>
<td>PM(<em>{2.5}), PM(</em>{10-2.5}), PM(_{10}) (Light scattering)</td>
<td>Does not require site visits; limited resolution</td>
</tr>
</tbody>
</table>

* Candidates for improved neighborhood and local measurements
Guidance on Indoor Air Cleaner/Filtration Systems

- Studies have shown that air cleaner/filtration operation in homes during wildfire periods help to reduce indoor concentration of PM2.5 (Barn et al., 2008; Henderson et al., 2005; Fisk and Chan, 2016)

- Both portable air cleaners and in-duct air filtration systems are available on market

<table>
<thead>
<tr>
<th>Particles Removal</th>
<th>Gaseous Contaminants Removal</th>
<th>Ozone Emission</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Device Type</strong></td>
<td><strong>Applicable Standard</strong></td>
<td><strong>Device Type</strong></td>
</tr>
<tr>
<td>Portable air cleaner</td>
<td>ANSI/AHAM AC-1-2019</td>
<td>Portable air cleaner</td>
</tr>
<tr>
<td>In-duct filter</td>
<td>ANSI/ASHRAE Std. 52.2-2017</td>
<td>In-duct sorptive media gas-phase air-cleaning devices</td>
</tr>
<tr>
<td>Portable energy-using air cleaners a</td>
<td>ANSI/UL Standard 867 (Section 37)</td>
<td>In-duct electronic air cleaners b</td>
</tr>
</tbody>
</table>

- Use portable air cleaner with sufficient Clean Air Delivery Rate (CADR) based on the room size.

- Use in-duct filter with sufficiently high Minimum Efficiency Reporting Value (MERV) under proper forced air system operation.

- May consider air cleaners that employ combined technologies to remove both volatile organic compounds (VOCs)/odors and particulates if volatile gaseous contaminants are also of concern.

- Avoid using ozone-generating air cleaners.

(a) Required by the current California’s Regulation to Limit Ozone Emissions from Indoor Air Cleaning Devices (Nov. 2008)
(b) Required in the proposed amendment to the current California’s Regulation to Limit Ozone Emissions from Indoor Air Cleaning Devices.
Current EHL wildfire emissions analyses

• 2017-2018 SF Bay Area air data and sample analyses
  • Public data: UV absorbing PM, black carbon, continuous/low cost sensor PM$_{2.5}$
  • New measurements: Electron microscopy and ICP-MS of ultrafine particles, coarse PM, ash, VOCs, and metals
    • Passive PM samplers and home furnace/air cleaner filters
    • “Tar ball” particles with trace copper, zinc, and lead
EHL Consultations & Trainings

• **Chemical release/wildfire trainings** on technical issues for health care coalitions (HCC), wildfire professionals, and other agencies
  
  • HCC chemical preparedness meetings & distance learning
  
  • Vulnerable CA hospitals - chemical release training
  
  • **Webinar series on wildfire emissions for wildfire professionals** (Fall 2018)
    
    • Impacts on hospitals, cleanup/recovery, first responders, worker health
    
    • Presenters from CDPH, Kaiser Healthcare, UC Davis emergency medicine, US EPA R9 cleanup operations, Oakland Fire Dept
Conclusions

• **Unique chemical components** of wildfire smoke
  - may impact human health differently than non-wildfire PM
  - may require improved measurements

• AQI based on PM2.5, low cost sensors, or conventional monitoring methods
  - may not account for metal-rich ash, ultrafine particles, or toxic gases from wildfires

• CDPH EHL characterizing wildfire emissions
  - **Particle size effects** on inhalation, transport, and fate
  - Outdoor air samples, ash, indoor air and furnace filters, and building materials analysis with microscopy, micro-spectroscopy, and ICP-MS.
  - Publicly available air data -> components specific to wildfire exposures
  - Technical assistance to other agencies

• **Goals:** reduce exposure misclassification and improve public health protection