Carbon Monoxide Diffusion through Walls:
A Critical Review of Literature and Incidents

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What is carbon monoxide (CO)?

- Tasteless, odorless, colorless, HIGHLY TOXIC gas
- Forms when there is not enough oxygen to produce carbon dioxide CO₂ (e.g. stoves, internal combustion engines operating inside enclose spaces)
- Combines with hemoglobin and takes the place that is normally reserved for carrying oxygen
- Causes headaches, nausea, loss of consciousness, death
Reported incidents of CO transport

- 4 incidents where CO travelled from restaurant kitchens into adjacent apartments
  - Ovens and grills from the restaurants left smoldering overnight with ventilation off, produced CO that travelled into the apartments above the restaurants
  - No communicating opening between the restaurants and apartments
- 1 incident in hotel where CO buildup formed in an exhaust shaft because of the natural gas heater of a swimming pool;
  - CO travelled through the walls into an adjacent room with no communicating opening to the shaft
  - 2 employees were affected by poisoning
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ATTRIBUTED TO DIFFUSION
What is diffusion?

DIFFUSION

= movement of a substance from an area of higher concentration to an area of lower concentration; results in mixing and mass transport, without requiring bulk flow

Diffusivity = material property dependent on the membrane and the gas that diffuses through it
Experiments from JAMA paper by Hampson et al. (2013)

- Plexiglass chamber over wooden frame
- CO infusion side
- 2.44m (96”)
- Control side
- Gypsum wallboard sample (various thickness)
- Junctions sealed with silicone caulk
- 0.61m (24’’)

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- Bypassing
- Leaks
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- 2.44m (96”)
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- gypsum wallboard sample (various thickness)
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**Diagram:**
- **LEAKS**
- **DIFFUSION THROUGH GYPSUM BOARD**
- BYPASSING
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Mass transfer model

• 1D mass transfer model to verify the validity of experiments (length>>width)

• Diffusivity is measured on both sides of the tank using raw data from experiments of Hampson et al. (time, CO concentration)

\[ D_1 = \frac{-VL}{2At} \ln \left( \frac{2c_1}{c_1^0} - 1 \right) \]

\( V = \) volume of tank [m\(^3\)], \( L = \) thickness of gypsum board [m],
\( A = \) area of gypsum board [m\(^2\)], \( t = \) time [s],
\( c_1^0 = \) initial CO concentration in the infusion chamber,
\( c_1 = \) concentration in infusion chamber at time \( t \)
Diffusivity values from mass transfer model and from literature
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Molar mass:
- $\text{C}_8\text{H}_{18}$ : 114g/mol
- $\text{CH}_3\text{-COO-CH}_2\text{-CH}_3$ : 88g/mol
- CO : 28g/mol
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Ethyl acetate and octane: heavier than CO, CO diffuses more easily.
Diffusivity values from mass transfer model and from literature

- **CO**
  - (Cleary, 2014)

- **CH₃-COO-CH₂-CH₃**
  - (Blondeau et al, 2003)

- **C₈H₁₈**
  - (Blondeau et al, 2003)
Mass transfer model

![Graph showing mass transfer model results](image)

- calculated C1
- calculated C2
- measured C1
- measured C2

**CO Concentration C_1 [ppm]** vs. **Time [min]**

0 100 200 300 400 500 600
CO detection legislation

CO Legislation as of January 2014

- State Legislation Passed
- No Legislation Currently
CO detection legislation

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- Commercial Sleeping Occupancies
CO detection legislation

- Current model codes do not require CO detection if there are no “communicating” openings between a garage and occupied areas of the building:
  - 2012 edition of NFPA 101, 5000 and 1
  - 2015 edition of IFC, IBC and IRC
Conclusion

• Diffusion is confirmed to be the main transport of CO in Dr. Hampson’s experiments
• Rate of diffusion is surprisingly high
• 5 reported incidents of carbon monoxide intoxication which can be attributed to diffusion
• Experiments in literature that use various VOC that prove gases are able to migrate through the pores in the walls
• CO is a smaller molecule than these, it can diffuse at least as fast as those

Re-evaluation of the codes to see if the new findings warrant modifications
Acknowledgements: