House Fires: An Analysis of Hydrogen Cyanide in Smoke

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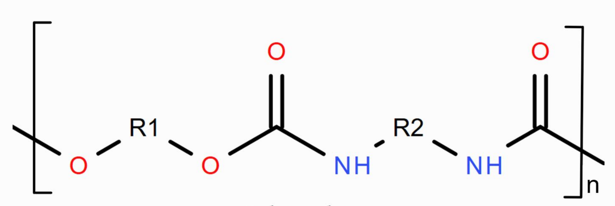
Introduction

The leading causes of death in house fires include smoke and soot inhalation; analyzing composition of said smoke is a top priority for treatment. Modern households contain increasing amounts of nitrogen-containing synthetic polymers in furniture, upholstery, and particle board. When under high heat and low oxygen, nitrogen rich polymers notably produce hydrogen cyanide (HCN) and carbon monoxide (CO). Key offending agents include polyurethane foam (found in upholstered furniture, mattresses, spray foam insulation, carpet, and adhesives) and urea-formaldehyde/cyanoacrylate (glue within composite woods).

Effect	HCN (ppm)
Headache, dizziness, vomiting, and weakness	20–40
Death within 30–60 min	120–150
Death after 10 min	200
Rapid death	300

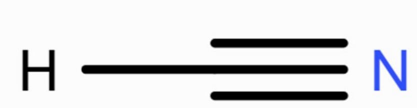
Polyurethane Foam

- Polyurethane foam (PUF) breaks down into toxic compounds when combusted or pyrolyzed:
  - HCN
  - CO
  - Nitric oxide (NO)



Polyurethane

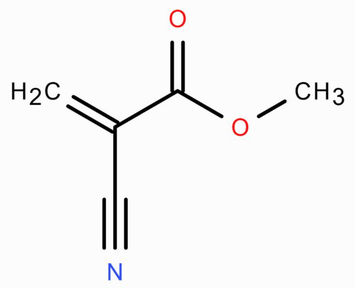
- Combustion of 100 milligrams of various PUFs yielded the following:
  - 100 $mg_{Foam\ A}$ → 1.49mg HCN
  - 100 $mg_{Foam\ B}$ → 1.11mg HCN



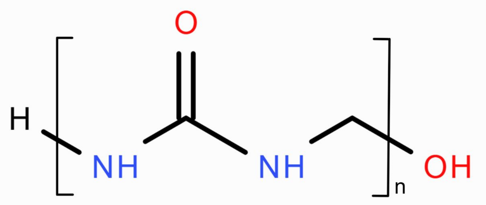
Hydrogen Cyanide

Urea Formaldehyde & Cyanoacrylate

- Breakdown of cyanoacrylate and urea formaldehyde forms multiple toxic products especially in temperature ranges from 200°C-500°C
- Products include: Hydrogen cyanide (HCN) and HCN precursors like isocyanic acid (HNCO)
- 100 $mg_{cyanoacrylate}$ → 1-10 μg of HCN
- 100 $mg_{urea\ formaldehyde}$ → 2-5 mg of HCN



Cyanoacrylate



Urea formaldehyde

Polyurethane
Urea formaldehyde $\xrightarrow[\text{Incomplete combustion}]{\downarrow O_2 \text{ environment}}$ Hydrogen cyanide (HCN)
Cyanoacrylate

Local firefighting agencies (Wichita, Derby, Sedgwick county, and Butler county) demonstrating their strategy for extinguishing structure fires and minimizing occupational exposure to smoke. Performed at their Regional Training Facility.

Pictured is one of the HCN detectors utilized by the fire departments during the training with a live reading. In training, the firefighters burn mostly organic materials, not high in nitrogen: hay, wood pallets (preferentially heat treated), and oriented strand board. The meter shows an HCN concentration of 16ppm with the materials chosen.

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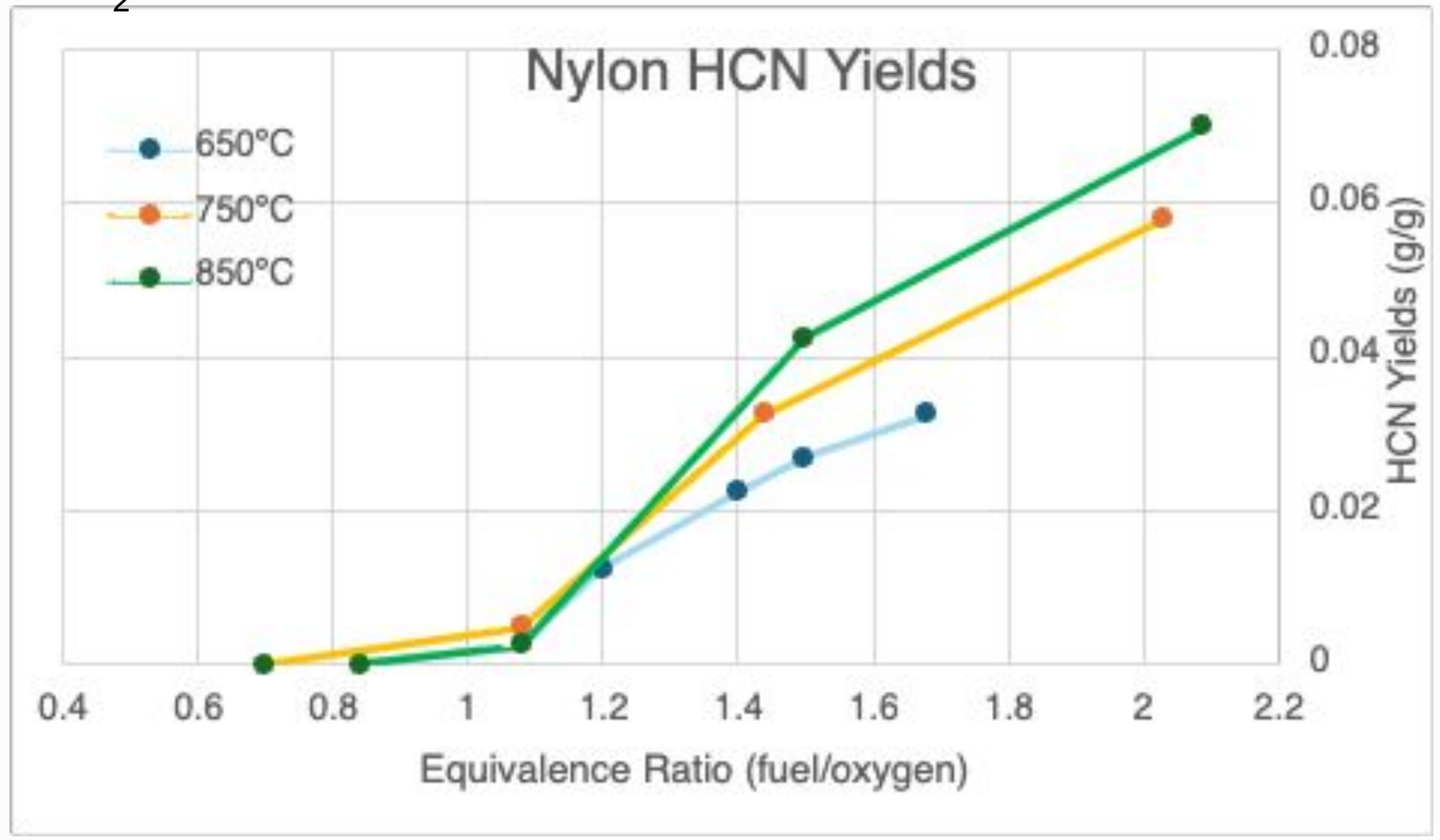
Cyanide Formation

Temperature
- Higher temperatures lead to increased hydrogen cyanide production

Oxygen
- HCN forms through incomplete combustion which occurs most readily in low-oxygen environments; less oxidation of fuel
- Complete combustion: $4CH_3CN + 15O_2 \rightarrow 8CO_2 + 6H_2O + 2NO_2$
- Incomplete combustion: $2CH_3CN + 3O_2 \rightarrow 2HCN + 2CO + 2H_2O$



Future

- Controlled burn with Derby, Wichita, Sedgwick County, and Butler County Fire Departments
  - Smoke analysis of combusted nitrogen-containing compounds with monitored temperature and ventilation
  - Updated protocol and safety guidelines
- Rapid field measurements of HCN in the blood

Conclusion

The partial combustion of polyurethane foam, urea formaldehyde, and cyanoacrylate contribute to the formation of HCN. The use of these materials in modern construction and household materials significantly contributes to the formation of HCN in smoke during house fires. High-temperature and low-oxygen conditions, typical of house fires, further promote the production of HCN.