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# Characterization of Particulate Emissions from a Hydrogen Engine

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**Introduction:** The conversion of existing internal combustion engines from burning hydrocarbon fuels to hydrogen has the advantage of virtually eliminating the emission of soot-based particulates (elemental carbon) formed by the combustion of hydrocarbon fuels thus decreasing the impact on human health. The emission of greenhouse gases (especially $CO_2$, and NO) is also reduced although there is still significant water vapor emitted. Recent studies show that trace metals are emitted by internal combustion engines and typically their origin is mainly from lubrication (lube) oil additives [1-2]. In this study we have sought to characterize the particulate emissions from a hydrogen burning engine and to investigate the contribution of lube oils to their composition.

**Methods:** A CAT 3304 engine modified to burn hydrogen gas was installed in an EIMCO model 975 mine utility vehicle, the Zero Emission Utility Solution (ZEUS). To investigate morphology and elemental composition of emitted particles, an Electrostatic Precipitator (ESP) was used to deposit particles on SiO filmed copper grids for analysis by Transmission Electron Microscopy (TEM) and Energy Dispersive Spectroscopy (EDS) attached to the TEM. To investigate size dependent particle composition, a 13 stage nanoMOUDI (Micro Orifice Uniform Deposition Impactor) was used to deposit size selected particles on the TEM grids at aerodynamic cutoffs of 75, 50, 32, 18 & 10 nm. For all EDS analyses, the SiO support film background and grid copper peaks were subtracted from particle spectra. Analysis of organic and elemental carbon (OC, EC) in the exhaust stream was determined by NIOSH Standard method 5040.

**Results:** TEM images of ESP and MOUDI samples were used to identify typical particle morphologies: spheroids, agglomerates and irregular particles, ranging in size of approximately 20-500nm. EDS results showed particle compositions containing C, O, Na, Mg, P, S, Ca, Sn, Fe, Zn. Note that all particle spectra show significant amounts of metals. A certified analysis of the lube oil used in the engine yielded these results in ppm: sodium-7, magnesium-72, phosphorous-1118, calcium-1871, Iron-19, zinc-877. Note that these same metals show up in the particles. Although the lube oil analysis was not designed to determine sulfur, the ash content in oil is thought to be its source. The tin (Sn) was determined to <1 ppm in lube oil analysis, but here it is thought to originate in an engine sub-system. The EC was determined to be 0% at idle, 2-5% at torque stall, and 2-10% at high load operating conditions, the remainder being OC.

**Conclusions:** We showed that for internal engine combustion in the absence of soot (EC) derived from hydrocarbon fuels, many particles are still emitted, and are mainly composed of OC and metals, and this reflects their origin from the lubrication oil used in the engine.

**References:**

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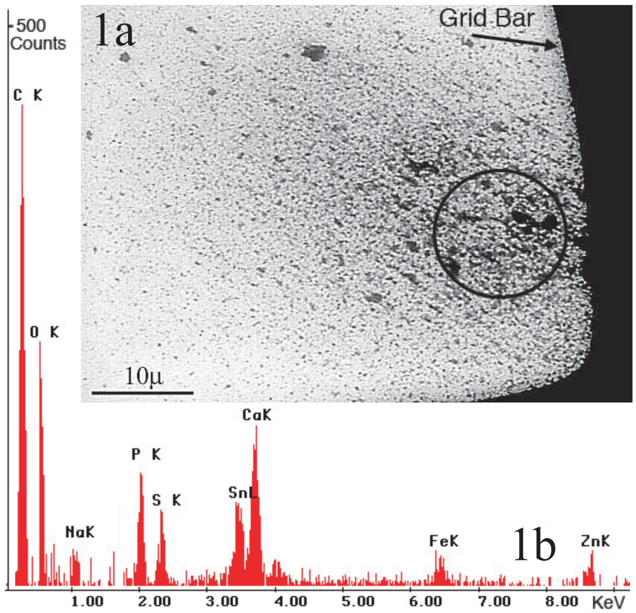


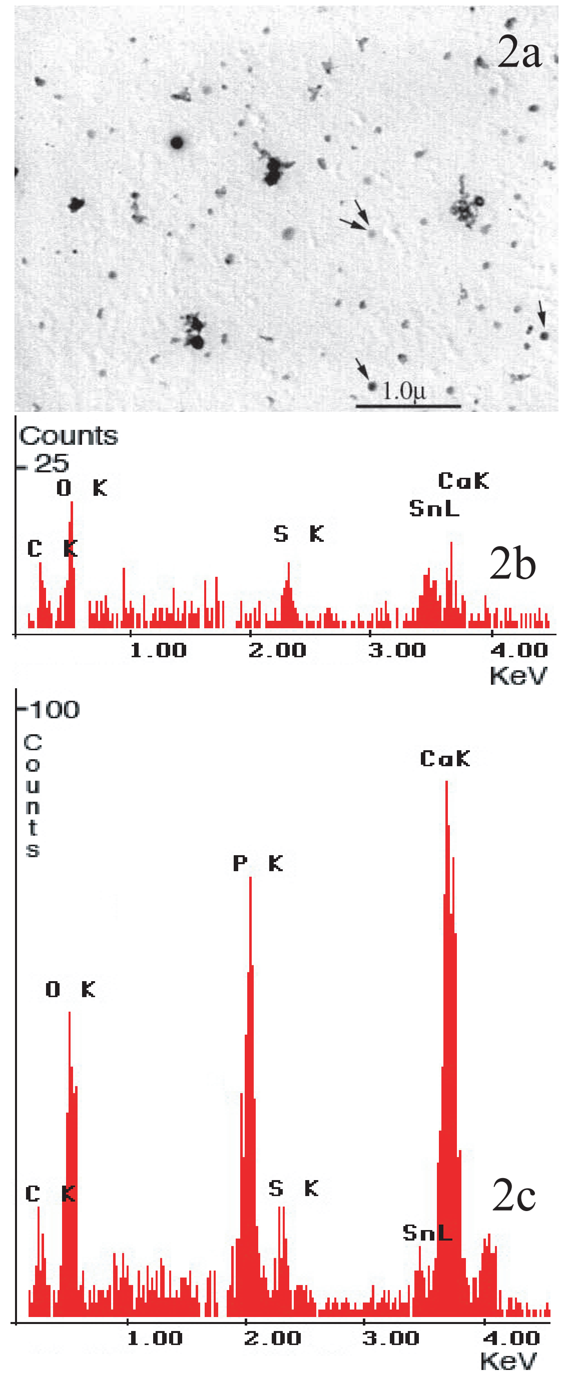


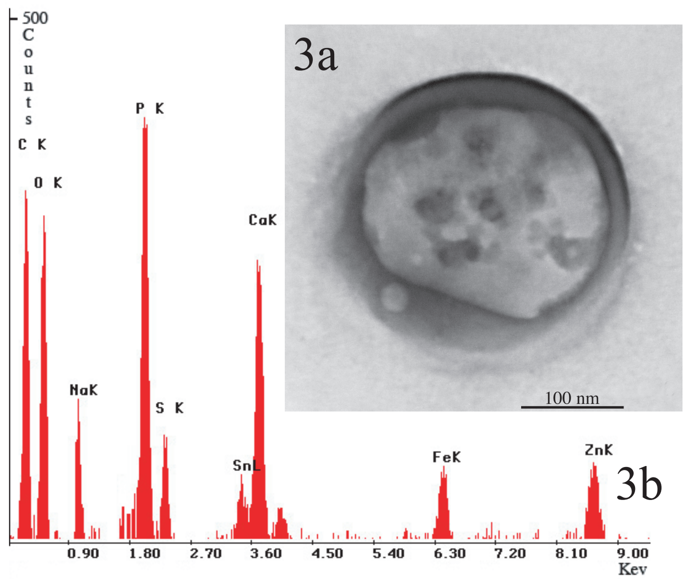


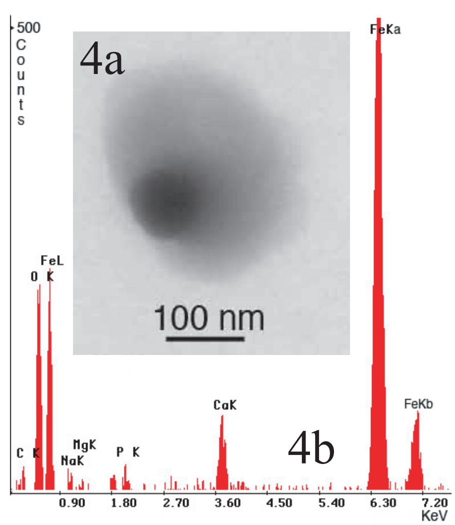


**Fig 1a.** MOUDI (75nm cutoff) particle plume deposited on SiO filmed TEM grid. **1b.** Spectrum of encircled area of high particle density shows average composition of plume. **Fig. 2a.** Low particle density area of plume shows variety of distinct particle morphologies. **2b.** Spectrum of low density spheroid (2x arrow) and **2c.** high density spheroid (1x arrow). **Fig 3a.** ESP. Typical complex particle whose spectrum **3b** shows variety of metals. **Fig. 4a.** ESP. Particle with dense core and low density shell. **4b.** Spectra of dense core shows high iron content. Low density shell has higher Ca (not shown).

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