Plasmonic Sensor and Field Monitor for Mercury

Jay James PhD

Picoyune

Picoyune MA-1 personal monitor

- Range: 0 to 20,000 µg/m^3
- Weight: 280 grams
- Battery: 16 hours
- Continuous
- Automatic
- Data logging
- Alarms
  - audible and visible
- First commercial plasmonic gas sensor

Picoyune MA-1 personal monitor

Executive Summary

We tested the accuracy and precision of six elemental Hg gas measuring devices, including Picoyune, Jerome 505, sorbent tubes (SKC No. 226-17-1A) using the NIOSH 6009 method, mercury monitor badges (Assay technology, 593 mercury vapor monitor) using the OSHA ID140 method, and two semi-quantitative colorimetric methods (Morphtech, No. 380018 and No. 382005) at both 25 $\mu g\ m^{-3}$ and 100 $\mu g\ m^{-3}$. A summary of the test results in provided in the summary Table below. Overall, the mercury sorbent tubes gave the best accuracy and precision, followed by the Picoyune.

Dr. Lowry, Carnegie Melon University

Plasmonic mercury sensing

- Localized surface plasmon resonance (LSPR): Noble metal nanoparticles exhibit peaks in absorbance that depend on the particles shape, size, and composition.

- Mercury vapor quantified by measuring changes in transmitted visible light through plasmonic film

$$C_{ext} = \frac{24\pi^2 R^3 \varepsilon_m{}^{3/2}}{\lambda} * \frac{\varepsilon_p''}{\left(\varepsilon_p' + 2\varepsilon_m\right)^2 + \varepsilon_p''^2}$$

Figure. Gold nanoparticles of different diameters in solution

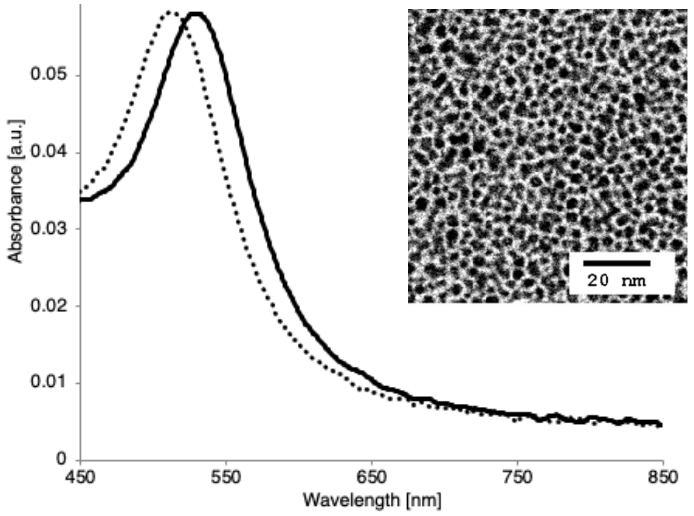
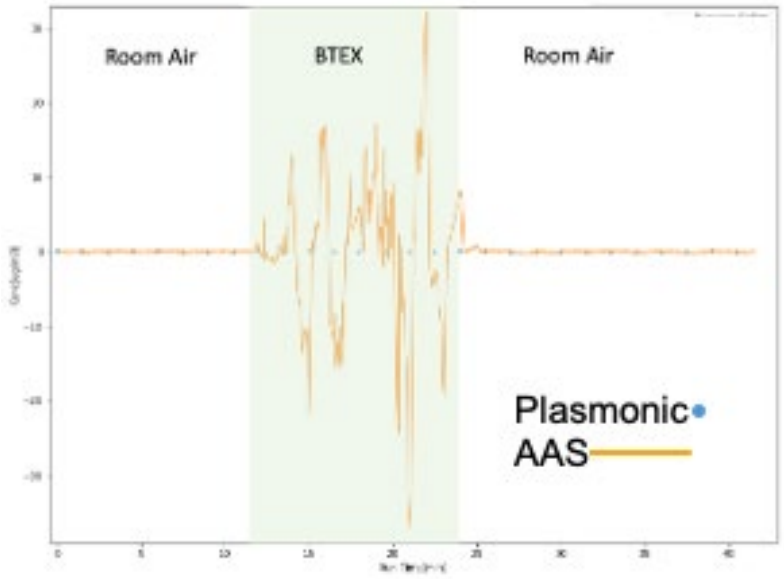
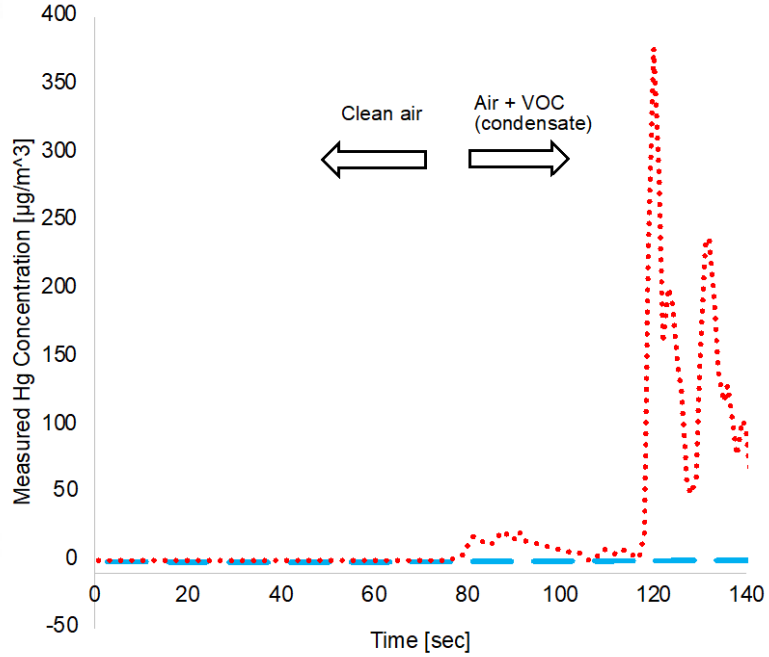


Figure. UV-Vis spectra of gold film pre- (solid) and post- (dashed) amalgamation showing the blue shift in the LSPR peak. (inset gold nanoparticle film TEM image)

No cross sensitivity to hydrocarbon vapors

- Selective adsorption/desorption (on/off)
- Controlled film temperature cycle
- Not sensitive to BTEX, VOC, SO_2, NOx, humidity, CO_2





Use cases

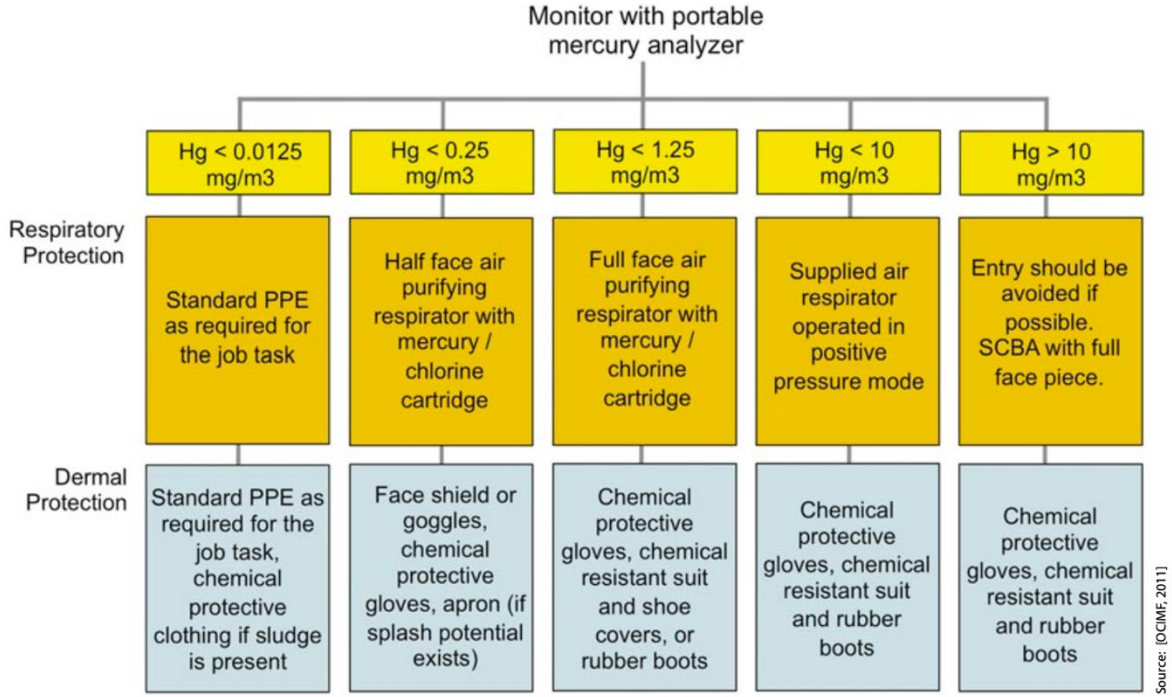
- Occupational exposure baseline (hot work and confined space)
- Facility mapping – going from unknown to known – plan ahead – reduce delays
- Downgrading PPE – prevent costs from excess protection level
- Defining contamination/hot zone
- Testing mercury impacted materials, prevent transfer of mercury from the contamination zone
- Real-time continuous exposure tracking
- Breaking containment

Work generates mercury vapor

- **Relying on measurements before work**
- Temporal variation – application of heat vaporizes and converts to Hg(0)
- Spatial heterogeneity – concentrations from a point source drop by the cube of the distance
- XRF shows high false negative rates – Hg under the immediate surface
- Mercury vapor concentrations in the breathing zone well above exposure limits during the hot work.

Field testing, comparison test, 2023

Benefits of downgrading PPE



Example of action-level matrix for PPE, IPIECA, 2014

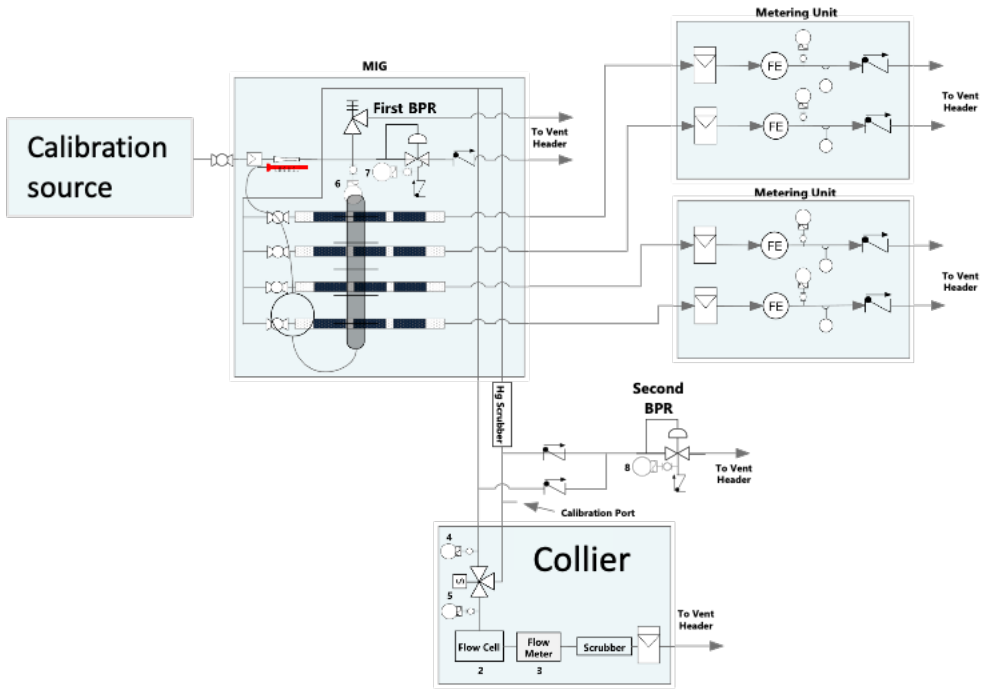
Plasmonic mercury monitoring of natural gas

- Continuous
- Direct
- Automatic calibration
- Small package
- 5 psi, 200 ml/min
- LOD 10 ng/m^3
- 0 to 20,000 µg/m^3

ATEX	Flameproof protection; II 2GD; Ex db IIC Gb; Ex tb IIIC Db; IP66/IP68; Tamb: -55°C to +85°C
IECEx	Flameproof and dust protection; Ex db IIC Gb; Ex tb IIIC Db; IP66/IP68; Tamb: -55°C to +85°C
CSA	Class I, Division 1, Groups A, B, C, D; Class II, Division 1, Group E, F, G; Class III; Ex db IIC Gb; Ex tb IIIC Db; Class I, Zone 1, AEx db IIC Gb; Zone 21, AEx tb IIIC Db; IP66/IP68/TYPE 4X; Tamb: -55°C to +85°C
UL	Class I, Division 1, Groups A, B, C and D; Class II, Division 1, Groups E, F and G; Class III; Class I, Zone 1, AEx db IIC Gb; Zone 21, AEx tb IIIC Db; Ex tb IIIC Db; IP66/IP68/TYPE 4X; Tamb: -55°C to +85°C
CE	EU and IECEx Attestation of Conformity

Enclosure ratings

Comparison to reference method



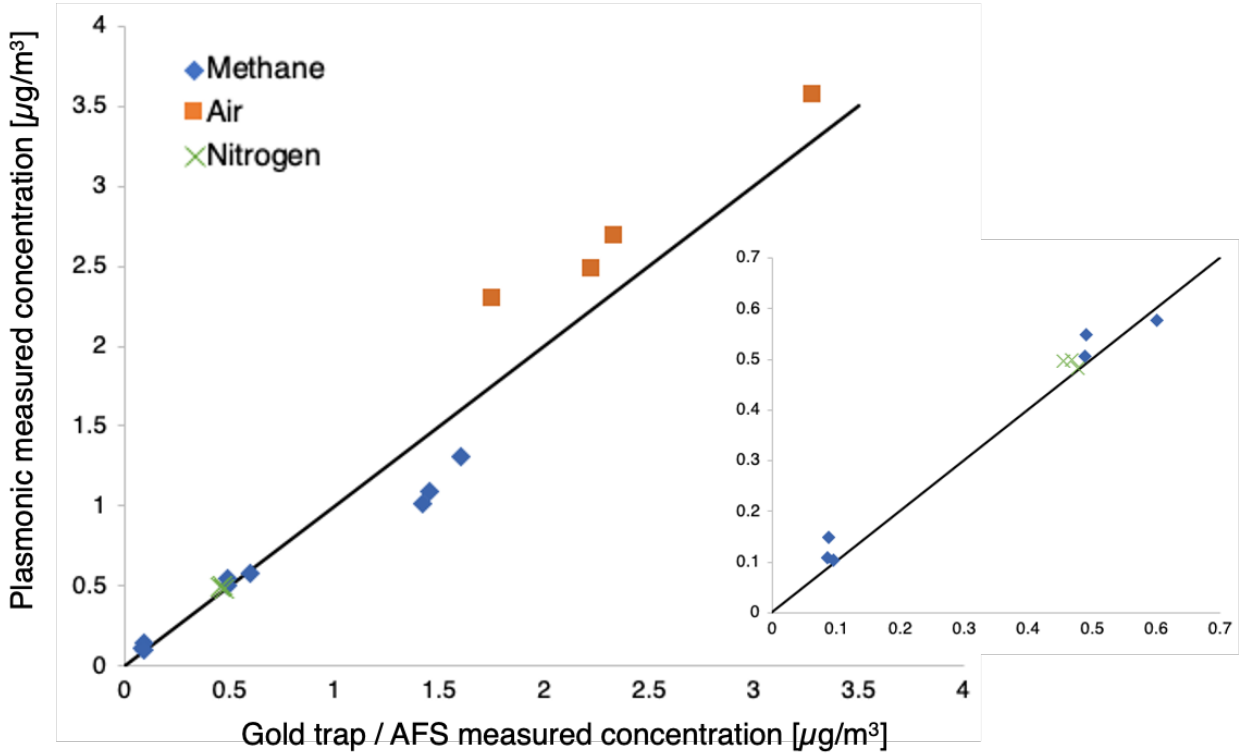


Figure. P&ID of MIG and Collier test bench

Conclusions

- Plasmonic mercury sensing enables new monitoring methods.
- Personal mercury monitors provide real exposure measurements for the highly variable and unpredictable atmospheres.
- Online mercury analysis can be simplified and lower cost by leveraging plasmonic sensors for direct measurement.

Grant Information	
Presenter	Jay James, PI, CEO
Technology Name and Description	The Picoyune MA-1 personal mercury monitor uses a novel plasmonic gas sensor. The plasmonic sensor is based on changes in transmitted light through a temperature-controlled gold nanoparticle film.
Innovation	Plasmonic gas sensors are smaller and more robust than standard atomic spectroscopic tools for mercury measurement. Our patented methods for plasmonic mercury sensing and plasmonic signal amplification allow trace measurements (ppt) at a fraction of the size and cost of previous tools. Our personal monitors identify and capture real exposure as we move and work.
Contaminant and Media	Current commercial instruments are for mercury vapor, and direct thermal measurement of mercury in solid and liquid samples is available for trial.
Technology Readiness Level	9, commercially available
Site Work	Carson River, Guyana, Peru, and many customers globally.
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