

PIDs And Aircraft Wingtank Entry

Aircraft maintenance requires workers to enter confined spaces that contain jet fuel vapors. As with all confined spaces, gas monitors are required to confidently decide if the atmosphere is safe for worker entry. Because of the physical qualities of jet fuel, specialized gas monitoring techniques should be considered. This Application Note discusses the following:

- Conventional LEL (Lower Explosive Limit) sensors were designed to measure methane and lack the sensitivity to accurately measure jet fuel vapors.
- Photoionization detectors (PIDs) are accurate and reliable hydrocarbon sensors and are uniquely suited for measuring jet fuel vapors.
- PIDs should also be considered to measure the toxicity of jet fuel and the other chemicals commonly used in aircraft maintenance.

Potential Users

- Aircraft Maintenance
- Jet Fuel Manufacturers
- Aircraft Manufacturers
- Military Aircraft
- Municipal Airports

Why Not Use A Conventional LEL Sensor?

While jet fuel is flammable, the LEL sensors found in virtually every confined space monitor do not have enough sensitivity to accurately measure jet fuel vapors. Workers can often see and smell jet fuel when in a wing tank, yet the meter does not detect it. This can seriously undermine workers' confidence in their monitor.

LEL Sensors Designed to Measure Methane

LEL sensors were originally designed to solve the problem of measuring methane levels in coal mines. Most LEL sensors use a Wheatstone bridge to measure the heat released when a flammable gas burns on a catalyst bead. The temperature rise causes a change in resistance, which is measured and converted to % LEL.

LEL Sensors Simplified

A Wheatstone bridge (catalytic bead) sensor is like a tiny electric stove with two burner elements. One

element has a catalyst (such as platinum) and one doesn't. Both elements are heated to a temperature that normally would not support combustion.



However, the element with the catalyst "burns" gas at a low temperature and heats up relative to the element without the catalyst. The hotter element has more resistance and the Wheatstone bridge measures the difference in resistance between the two elements. Effectively, this sensor measures the heat released when a gas burns.

LEL Sensor Limitations

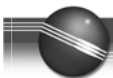
Four main factors affect the performance of catalytic bead LEL sensors in a wing tank entry environment:

1. Gases burn with different heat outputs ("hotter").
2. Gases have different LEL values, so some gases have more molecules present than others at the same %LEL.
3. "Heavier" hydrocarbons have difficulty diffusing through a flame arrestor to reach the LEL sensor.
4. Chemicals commonly used in aircraft maintenance can poison LEL sensors.

Overall Sensor Response

The overall sensor response is a combination of the first three factors. If the gas burns relatively hot, the response will be stronger. If the gas has a high LEL concentration, more gas will be present for a given %LEL and the response will be higher. If the gas is "heavy" (high boiling point and flash point), the diffusion rate is slower and less gas gets to the sensor per unit time, causing a weak response. The metal frit flame arrestor that limits the diffusion is necessary to make the sensor intrinsically safe and prevent the hot sensor itself from igniting an explosion. It does not prevent gases like methane, propane and ethane from reaching the catalytic bead. However, it severely limits the diffusion of heavy hydrocarbons like jet fuel, diesel, and some solvents.

The overall sensitivity of various gases compared to methane is listed in the table that follows. For example, ammonia has a higher response than methane because both are light gases, but the LEL for ammonia is higher. Jet fuel burns "hotter" than



methane, but the overall response is much weaker because jet fuel is much heavier and has a much lower LEL. If an LEL monitor is calibrated on methane and then is used to measure jet fuel vapors, the monitor will theoretically display less than one third of the true reading. In some practical cases, we have found even lower response with jet fuels and found that LEL sensors could not read diesel fuel vapors at all.

Gas/Vapor	LEL (Vol%)	Sensitivity (Relative %)
Acetone	2.2	45
Ammonia	15.0	125
Benzene	1.2	40
Hexane	1.1	48
Jet Fuel	0.3 – 0.9	≤30
Methane	5.0	100
MEK	1.8	38
Propane	2.0	53
Toluene	1.2	40

LEL readings can be corrected by choosing calibration gases that are more appropriate to the gas that you are measuring. It is difficult to obtain a compressed gas standard for jet fuel. Therefore, it is recommended that a “surrogate” calibration method be used. The chart above shows that the LEL response of hexane is much closer to jet fuel than methane. Some manufacturers calibrate their LEL sensors to hexane for this reason. However, the response to jet fuel is ≤68% of that for hexane. Therefore, when calibrated to hexane and reading 10% of LEL in a space containing jet fuel vapors, the true concentration is actually ≥16% of LEL.

Testing by independent labs like TRW has verified that catalytic bead sensors do not have appropriate sensitivity for jet fuel. Therefore, even when their output is boosted to allow for the low response of jet fuel, catalytic bead LEL sensors lack the sensitivity for measuring at the jet fuel levels necessary to protect workers making confined space entries.

LEL Sensor Poisons Used in Aircraft Maintenance

On top of the already weak response to jet fuel vapor, LEL sensor performance can be degraded even further by chemicals commonly used in aircraft

maintenance. The most serious poisons are silicon compounds. Exposure to just a few parts per million (ppm) of silicon compounds for several minutes is enough to severely degrade the catalyst and sensing performance of a catalytic bead LEL sensor. These compounds are used in a wide range of products, including lubricants, adhesives, silicone rubbers (including caulking and sealant compounds), and others. Chlorinated hydrocarbons are another common group of chemicals that degrade LEL sensor performance. They are frequently found in solvents, including degreasing and cleaning agents used in and around aircraft. See Technical Note TN-144 for more information on LEL sensor poisons and how to handle them.

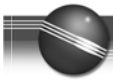
PIDs: A Better Jet Fuel Sensor

Portable PIDs are inherently much more sensitive to hydrocarbons than catalytic bead LEL sensors. In addition, they do not require an inlet frit flame arrestor to diffuse through, and thus have much faster response, on the order of a few seconds. Thus, response to jet fuel and diesel fuel is quite strong, about 1000 times more sensitive than the LEL sensor. Measurements at the 10% LEL action level are well within the linear range of the PID. Wing tank entries should not be made if the concentration of jet fuel in a wing tank is over 10% of LEL (this varies from 300 ppm to 900 ppm for various jet fuel vapors). As shown by the following table, one can see that PIDs will provide the most consistent readings for a decision at 10% of LEL.

Sensor	Display	ppm Equivalent
PID Display	800 ppm	800 ppm
PID low (-10%)	720 ppm	720 ppm
PID high (+10%)	880 ppm	880 ppm
LEL Sensor Display	10 %LEL	800 ppm
LEL Sensor low (-3%)	7 %LEL	560 ppm
LEL Sensor high (+3%)	13 %LEL	1040 ppm

Sensor accuracy affects user confidence. At 10% of LEL for methane, a PID is clearly the more accurate sensor:

- PID range of uncertainty: 160 ppm
- LEL sensor range of uncertainty: 480 ppm



So a catalytic bead LEL sensor is not only less sensitive, it has a three times wider error range than a PID for measuring 10% of jet fuel LEL.

Measure ppm of Jet Fuel for Toxicity

The ACGIH (American Conference of Government Industrial Hygienists) recently established an 8-hour TWA-TLV (threshold limit value) of 200 mg/m³ (approximately 35 ppm) for kerosene products. Most jet fuels are kerosene mixtures that fall under this exposure limit. In order to attain this level of protection, confined space monitors that measure jet fuel in low ppm levels are required. PIDs offer a compact, reliable solution to the problem of protecting technicians who have to work in or around jet fuel. Catalytic bead LEL sensors have a detection limit of about 1000 ppm for kerosene and cannot possibly measure in the TLV range.

PID Action Levels (at 35 ppm toxicity):

- Worker can enter wing tank without respiratory protection if PID is below low alarm (35 ppm)
- Worker can enter wing tank with respiratory protection if PID is above low alarm but below high alarm (between 35 and 600 ppm)
- Worker cannot enter wing tank if PID displays any high alarm (above 600 PPM or 10% of LEL)

PIDs Protect Maintenance Personnel from Chemical Exposure

Many chemicals are used in aircraft maintenance, including paints, degreasers, and solvents. The PID is a total hydrocarbon analyzer that measures all of these chemical vapors. While a PID can't differentiate among common hydrocarbons, if the PID alarm is set for the "worst" chemical, then a worker will be safe in the presence of all the other chemicals. The following chart shows that if the low alarm is set to 35 ppm for jet fuel, the PID will assure safety around many of the chemicals commonly used on aircraft.

The "Exposure Limit in Isobutylene Equivalents" column puts all setpoints on an equal basis by taking into account the different sensitivities a PID has to

Jet A/ JP-8	0.67	34	51
Jet B/ JP-4	1.0	30	30
JP-5	0.6	29	48
Jet Fuel TS	0.6	30	50
Acetone	1.1	250	227
MEK	0.86	200	233
MPK	0.93	150	161
TCE	0.54	50	93
PCE	0.57	25	44

various chemicals. This column shows that Jet B/JP-4 has the lowest exposure limit in "equivalents." This means that this jet fuel is the "worst" chemical and the alarm should be set to 30 ppm.

Definitions:

- **CF:** Stands for *Correction Factor*. CF is a measure of the PID's sensitivity to a particular gas or vapor. The lower the number, the greater PID sensitivity is to that compound.
- **Exposure Limit:** as defined as the lowest of the ACGIH, OSHA or NIOSH limits or other agency (refer to "Permissible Exposure Levels for Selected Military Fuel Vapor," National Academy Press).
- **Exposure Limit in Isobutylene Equivalents:** The ACGIH/OSHA/NIOSH TWA is converted to the equivalent reading on a meter calibrated to isobutylene (Exposure Limit divided by CF).

PID Benefits for Aircraft Work

A PID has the ability to measure jet fuel at low levels below 1 ppm. No other technology currently available has the ability to reliably measure jet fuels at these low levels (for more info on PIDs, reference RAE Systems publications AP-211: "PIDs for Continuous Monitoring of VOCs" and Technical Note 106: "Correction Factors, Ionization Energies and Calibration Characteristics"). This unique ability provides the following benefits for aircraft maintenance:

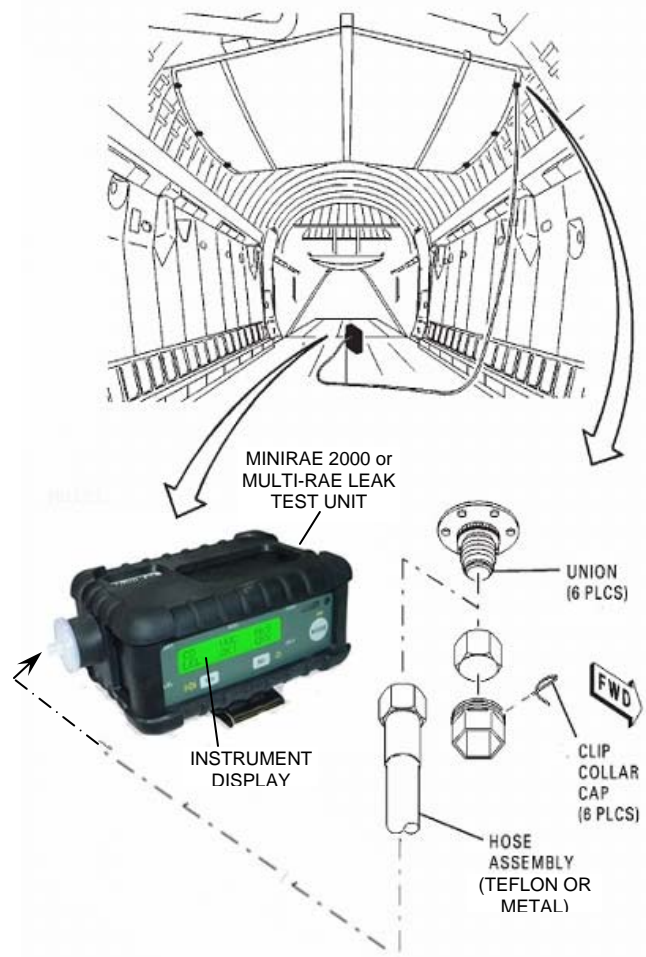
- **Get Into Wing Tanks Sooner.** Measuring at ppm levels allows workers to enter wingtanks as soon as levels drop below 30 ppm rather than waiting a prescribed period for mechanical ventilation to remove fuel vapors (Boeing recommends

Chemical	CF	TWA-TLV Exposure Limit	Exposure Limit in Isobutylene Equivalents
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ventilating for 24 hours). This reduces aircraft time on the ground and can dramatically decrease total maintenance costs by increasing aircraft availability.

- **Ventilation does not assure that all vapors are removed.** Measuring at ppm levels can protect workers if temperatures rise while they are in a wing tank and pools of fuel start to evaporate.
- **Reduce or eliminate facemask usage.** Many wing tank entry programs call for the use of organic vapor masks to protect workers. But these masks reduce worker efficiency, particularly when crawling in tight, baffled wing tanks. Often they are not worn, because they are cumbersome, and workers go unprotected. The PID allows workers to enter wingtanks without a mask, yet know they are completely safe.
- **Reduce or eliminate colorimetric tube usage.** The PID can be used to measure for other toxic chemicals used around aircraft. This can reduce or eliminate requirements for other measurement techniques like colorimetric (“Dräger”) tubes or industrial hygiene sampling techniques.
- **Track Down Fuel Spills.** Traditionally environmental firms have been called in to assess the damage caused by inadvertent fuel spills. The PID used for worker protection can also be used to survey soil and water for fuel contamination.
- **Perform Wing Shell Tank Testing.** The figure on the right shows a typical leak test setup for wing shell tanks using a PID. A typical test procedure is as follows:
 - Unions are installed in 6 test locations on the tank.
 - Ensure that no liquid is in the union port.
 - Connect Teflon or metal tubing to the port and the PID instrument.
 - Sample for 5 to 10 minutes before recording the measurement, allowing exhaust to vent out the aircraft door.
 - Readings up to 2000 ppm are acceptable.
 - Readings between 2000-5999 ppm: aircraft can be flown to maintenance facility for repair.
 - Readings above 6000 ppm: aircraft cannot be flown and must be repaired on site.
 - If the instrument cannot read up to 6000 ppm, use a calibrated dilution fitting to extend the instrument range.

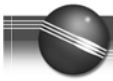


Effects of Negative Pressure on PID, LEL, CO and H₂S Sensors

RAE Systems performed testing on the MultiRAE to evaluate the performance of the PID, toxic, combustible and oxygen sensors in the MultiRAE Plus under negative pressure conditions found during wing tank leak testing.

Pressure	PID	LEL	CO	H ₂ S	O ₂
0 psi	97.5	50.3 %	48	7.2	20.8%
-2 psi	97.4	47.8 %	48	7.1	20.7%
-5 psi	96.4	45.1 %	48	6.0	20.2%

Based on this test data, the PID, oxygen and toxic sensors were not affected significantly by negative pressure to -5 psi. The combustible gas sensor may see a slight drop of sensitivity by about 5% under slight negative pressure conditions (-2 psi).



Never Use Tygon Sample Tubing for Jet Fuel

Because soft rubber sample tubing such as Tygon quickly absorbs jet fuel, it should *never* be used when sampling from spaces that contain jet fuel. Only metal, Teflon, or Teflon-lined Tygon tubing should be used.

Summary: PIDs - The Next Generation of Gas Monitoring for the Aircraft Industry

PIDs provide an accurate, reliable poison-resistant means of measuring gas vapors for both explosivity and toxicity. This chemical resistance coupled with their superior sensitivity to hydrocarbons, like jet fuel, makes them the better choice for measuring jet fuel LEL, compared with methane sensors, which have traditionally filled this role in aircraft maintenance. The US Navy, Air Command Canada and many commercial carriers and maintenance facilities have already integrated PIDs into their confined space entry programs.

RAE Systems PIDs for the Aircraft Industry

ToxiRAE Pocket PID

An affordable PID that fits into a shirt pocket and can easily fit into cramped wingtanks. The ToxiRAE PID is for those who already have a confined space monitor but need the benefits of measuring ppm of VOCs.

MultiRAE Plus Multi-gas Monitor with PID and MiniRAE 2000 PID

The MultiRAE has a PID (VOC) detector in addition to oxygen, LEL, two toxic gas sensors like CO and H₂S, and an internal pump. The MiniRAE 2000 is a high-performance PID with range up to 10,000 ppm.

- **Lightweight.** 16 oz (454 g) (MultiRAE) or 19 oz (532 g) (MiniRAE 2000) with battery.
- **Rugged Design.** ABS plastic construction, RFI shielded, drop tested for UL approval.
- **Backlight Display.** For low-light conditions.
- **Quick Response.** Pump flow rate >200 cc/min for MultiRAE and >500 cc/min for MiniRAE.
- **Remote Sampling.** Up to 200 ft (60 m).
- **Pump Shutoff.** Alarm and pump shut off when detecting a blockage, to avoid sucking in liquids.

- **Li ion, NiCad or Alkaline Batteries.** 10 hours on a full charge; ability to switch to alkaline.
- **Continuous Operation.** on 110VAC, 220VAC or 12 VDC.
- **User Programmable Alarms.** Preset alarms with user-program capability.
- **High Sensitivity.** Resolution of 0.1 to 1 ppm, depending on sensor and compound.
- **Range.** 0.1 to 2000 ppm for MultiRAE and 0.1 to 10,000 ppm for MiniRAE 2000.
- **Negative Pressure Tested.** Units perform under -2 psi; useful for leak detection testing.

References

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RAE Systems: Technical Note TN-106: Correction Factors, Ionization Energies and Calibration Characteristics

RAE Systems: AP-211: PIDs for Continuous Monitoring of VOCs

RAE Systems: TN-144: Handling LEL Sensor Poisons