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Detect, Measure, Analyze.

Thank You for Attending Today's Webinar:

Emissions and Combustion Testing 201:
Best Practices in Testing and Portable Analyzer Care

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Portable Emission Analyzer Testing: Best Practices 102

Presenter Jordan Love and Billy Lyne
Testo Inc. and Raeco LLC
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Agenda

- Best testing practices
- Sensor technology
  - Benefits
  - Limitations
  - Cautions
- Testing
  - Sample conditioning
  - Hardware considerations
  - Reporting

Best Testing Practices

The tester must have the knowledge and the analyzer has to have the proper hardware to be successful at combustion / emissions testing.

- Cross-sensitivity (to other gases)
- Temperature Influences (drift)
- Flow / Pressure sensitivity
- EC specific include:
  - Sensor Saturation
  - Sensor Aging
- Sample handing and conditioning
- Calibration procedures

How does a tester overcome limitations and measurement variability?

Both emissions analyzer and tester need to understand and address:

- Physical effects (i.e. temp, flow rate, cross sensitivity)
- Sample transport and sample conditioning
- Actual stack concentrations
- Data reporting objectives
- Calibration quality (procedures)

The solution for greatest accuracy

- Know your stuff and address those specific limitations
- Use procedures that eliminate the sources of variability

What is an Electrochemical sensor?

- An electrochemical sensor is a device that develops an electrical response when exposed to certain (gas) compounds. It is similar to a battery in that it typically contains electrodes of different metals, and has an electrolyte
- The output is proportional to concentration

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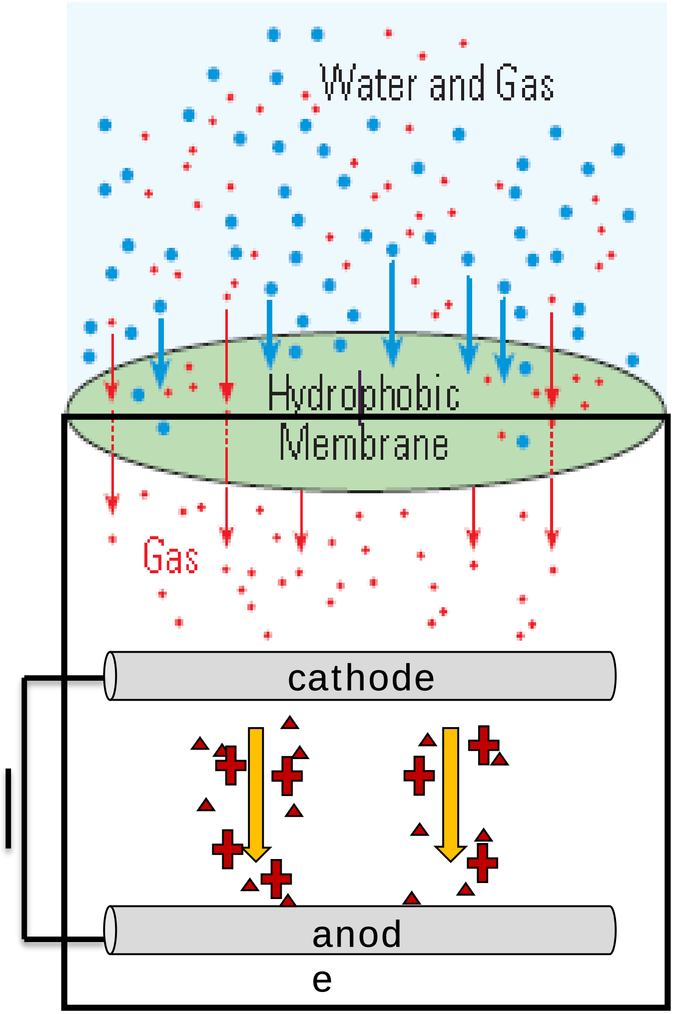
Types of Electrochemical Sensor

- 1962 Clark O2 sensor- diabetes monitoring sugar oxidation @ electrodes)
- More than 30 manufacturers
  - Citi Technologies
    - Membrapor
    - Drager
    - Alphasense
    - Sensor Tech, etc.
- Different designs and materials change the testing range, sensitivity, and life expectancy

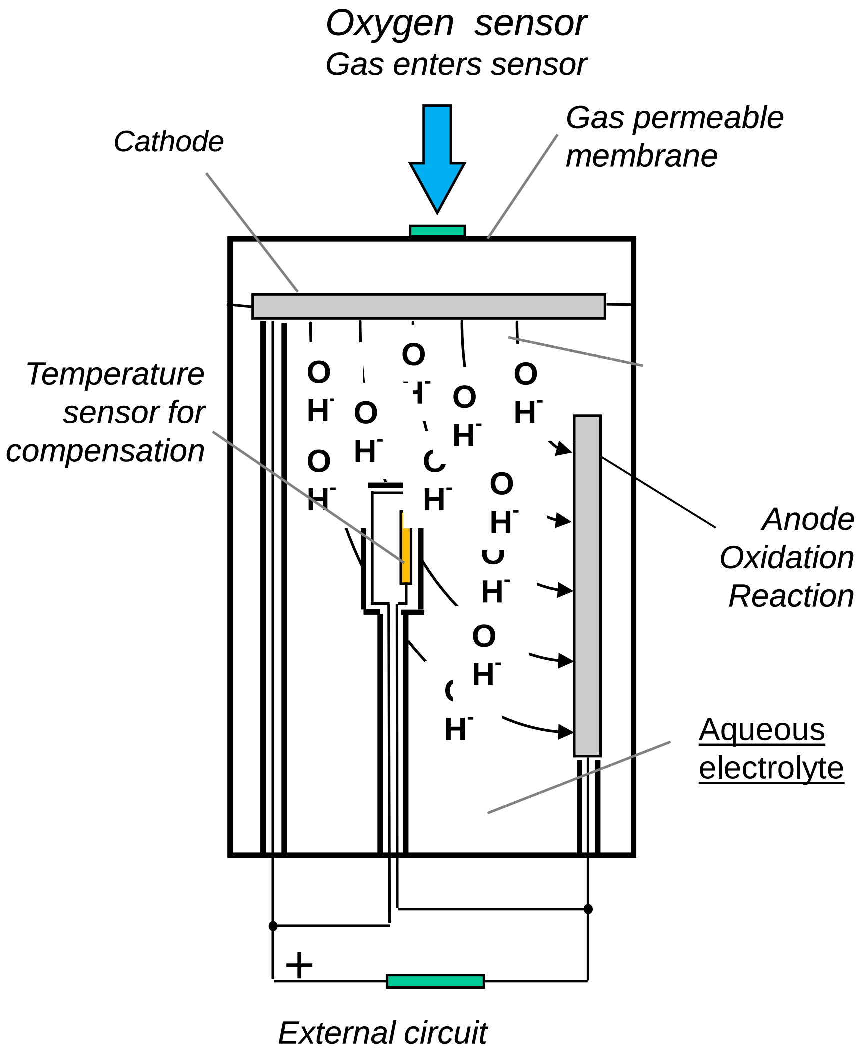

Each sensor type is target gas specific with different - Chemistry, Electrode materials, Geometry, & Electronics.

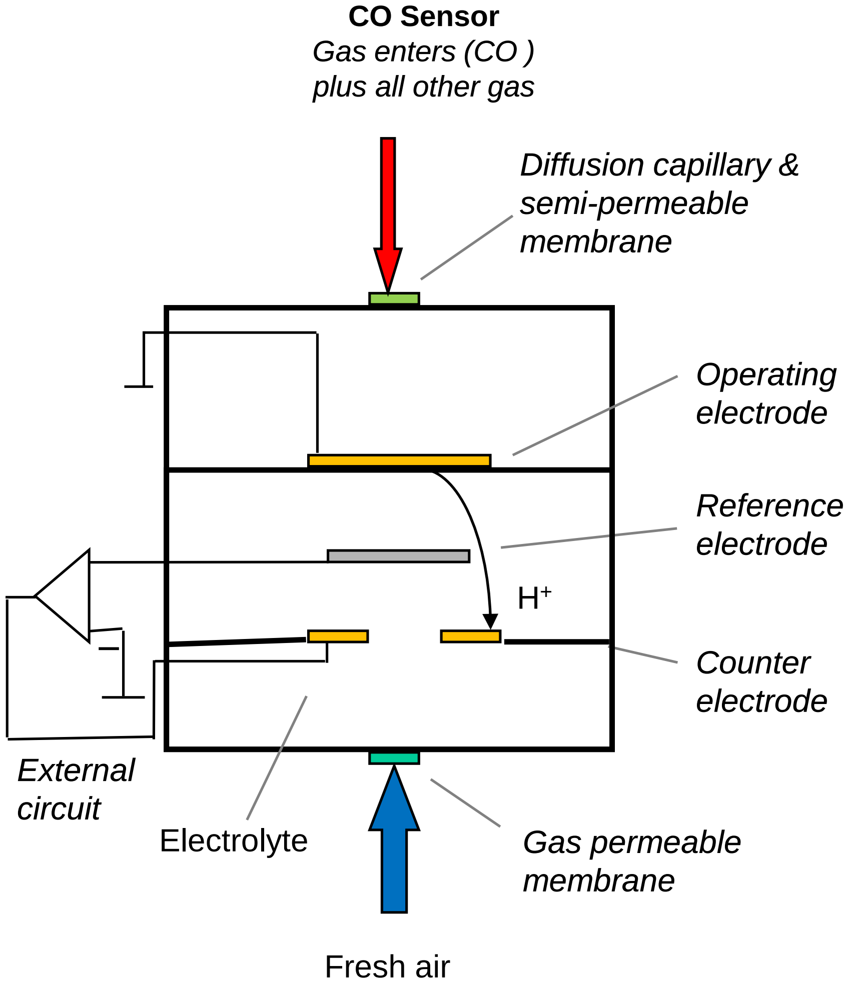
Sensors designed for emission testing

- Semi-Permeable Membrane
  - Stops free water (hydrophobic)
  - Stops particulates
  - Maintains moisture equilibrium in electrolyte
  - Diffuse gas into sensor
    - Teflon w/defined capillary action, or
    - Defined pore hole
- Gas reacts on electrodes (cadmium, lead, gold, or platinum) and produce electric particle (ie. -OH or +H ions)
- Particle transfers charge through electrolyte
- Reaction on 2nd electrode



Electrochemical Sensors





Benefits of Electrochemical (EC) Technology

- Targets useful parameters - O_2 CO NO NO_2 and more
- Linear output - *reproducible and predictable*
- Large temperature range (well characterized)
- Stable standard calibration
- Not sensitive to vibration
- Insensitive to stack moisture - some exceptions
- Not sensitive to barometric or elevation change
- Cross-utilize - combustion tuning & emissions testing
- Accurate – within EPA perf. Spec ppms (ppb in ambient)

But…all measurement technologies have limitations – EC No different

- Useful parameters: O_2, CO, NO, NO_2
  - *but not continuous from single sensor – time & concentration limited*
- Direct NO_2 reading with no converter losses
  - *but, EC sensor high accuracy may mean higher NOx readings when compared to CLD as reference*
- Sensors do better in exhaust stack than on calibration gas.
  - Calibration gas lack the ingredients for best sensor response
- Low power requirements allow portability
  - *Portability encourages changes in ambient conditions and large changes could impact "compliance level" accuracy*
- Cross-utilized for emission testing and tuning
  - *But tuning exposes sensors to "as found" scenarios with higher probability of high concentrations and sensor overload*

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Interference & Cross Sensitivity

Table 6–1. Typical Interferences Found in CEM System Analyzers

Technique	Typical Interferences
Infrared SO_2, NO, CO_2, CO	H_2O, CO_2, CO, Temperature
Luminescence SO_2, NO_x	CO_2, O_2, N_2, H_2O, Hydrocarbons (Quenching)
Ultraviolet (UV) SO_2 NO	 NO_2 SO_2
Electrochemical	Varies with cell EMFs
Electrocatalytic ZrO_2 cells for O_2	CO, Hydrocarbons
Paramagnetic O_2	NO

Lets talk about how you use the analyzer so you do not have these problems

EPA CEMS Operators Guide - Chapter 6 Source of Bias in Gas analyzers
http://www.epa.gov/airmarkt/emissions/docs/bias6.pdf

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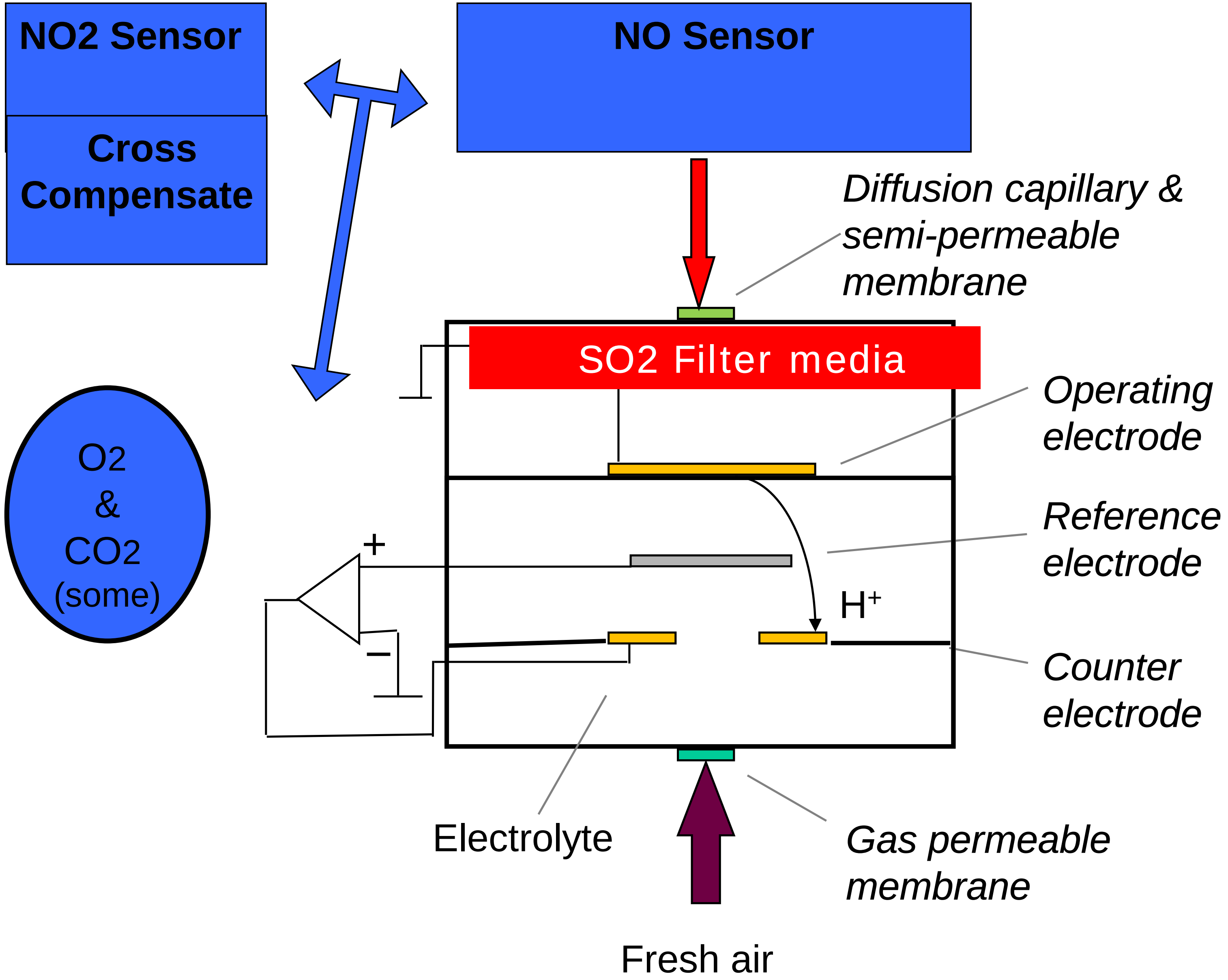
Cross sensitivity - CO sensors

- Electrochemical CO Sensor
  - Positive cross sensitivity to NO
  - Non-filtered CO sensor will respond (positive) to NO
  - Go to video clip (you tube) **Testoinstruments** is our channel (No space)
- Solution – Filter out unwanted gas with the NOx filter
  - pink/purple media (potassium permanganate)
  - External NOx beads (not a moisture desiccant)
  - Internal filter bed

Change and maintain per manufacturer spec.

Cross sensitivity – filter or measure & cross-compensate



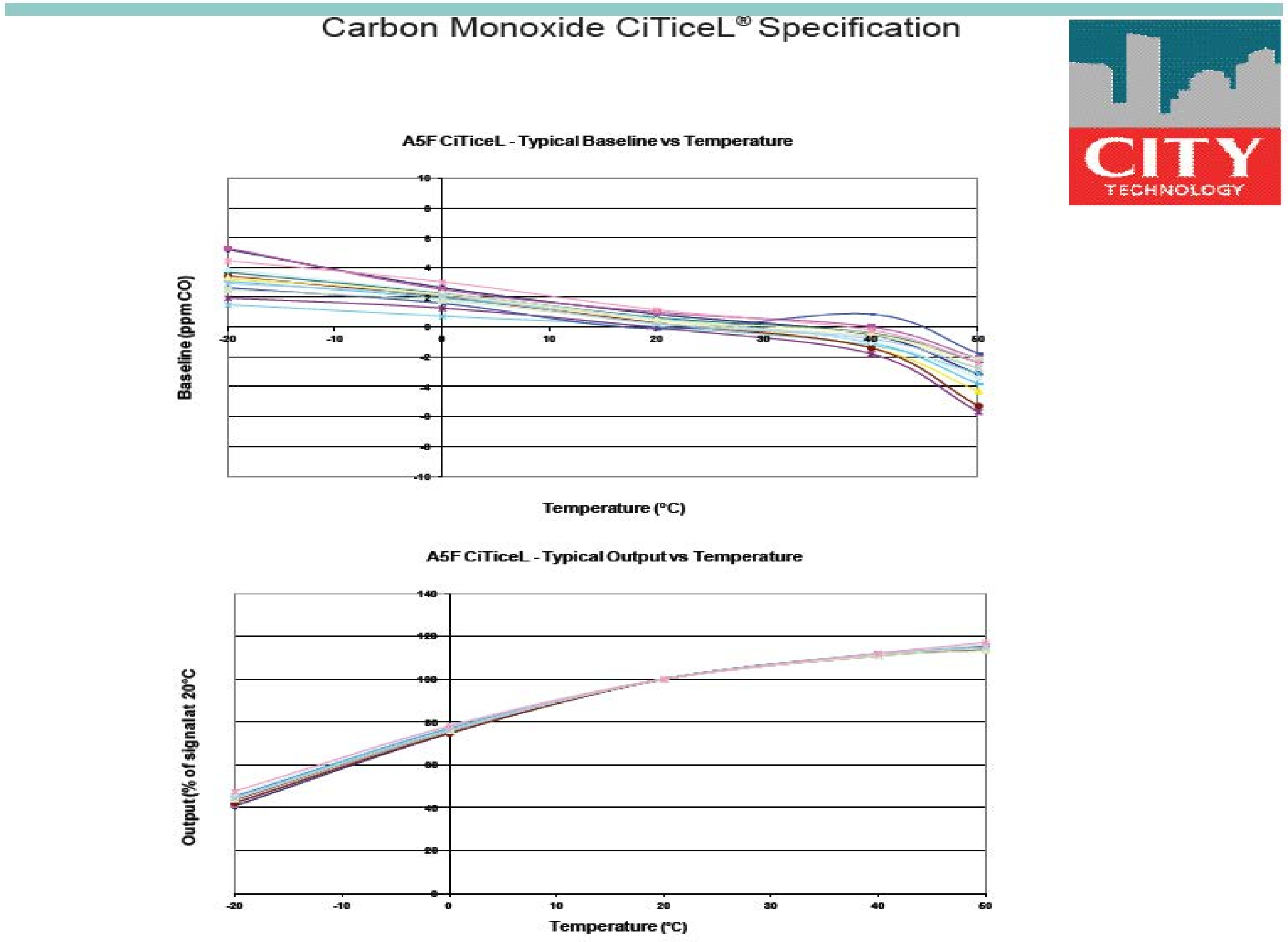
CO sensors & H2 cross sensitivity

- Electrochemical sensors
  - Cross sensitive to H_2 (**up to 60% positive reaction**)
  - H2 forms as combustion degradation by-product. Forms extensively at, and below 1% O_2 concentrations.
  - Ambient CO sensors used for H_2 monitoring applications
  - Rich burn exhaust can have more than 1000 ppm H_2
    - *In this case - potentially adds up 600 ppm to CO reading*

- *Testo's Solution* – Use H2 compensated sensor
  - Uses 4 internal electrodes instead of 3 electrodes
  - 4th electrode is used to react with H_2.
  - Use electronic cross compensation (performed at sensor base level) to eliminate false positive readings

Temperature Influences

EC sensors in raw form will drift as temperatures change. However the temperature profiles and behavior are well documented and characterized. 1000 of sensor in use.



In search of the perfect measurement

Solutions to minimize temperature influence

- Best – use complete temperature control
  - Nema/CEMs enclosures $50K
- Best portable way - Testo uses continuous temperature compensation
  - On each individual sensor
- For best compliance results, keep analyzer thermally stable through out calibration and testing
- Other ways
  - use temperature control
  - Inside truck, with digital Htg & Cooling controls
  - shaded from ambient

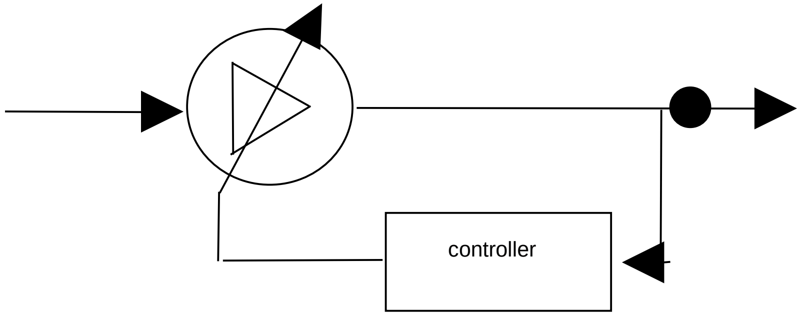
In search of the perfect measurement – *Pressure and Flow Rate*

- EC sensors use diffusion as means to expose sensing electrodes to the exhaust sample.
- Emission grade analyzers, control the flow rate/pressure through special manifolds, orifice tubes and pumps. (note: extremes could overwhelm and impact the diffusion rate and sensor output)

- ***Solution*** – Control sample flow rate and monitor
  – Some analyzers have manual flow control devices others have orifice plates and monitor and others have electronically controlled pumps
  – <u>Testo's solution is automatic flow rate control</u>
  – All test methods require some type of flow rate monitoring specification typically to be within 10% between Calibration and source testing flows.

testo 350 – Flow-controlled sample gas pump

- **Large powerful pump with constant flow control**
  - 1 liter/min flow-controlled regardless of hose length and filter conditions
- **Benefit –**
  - Will automatically keep analyzer within the testing protocol specifications (CTM, ASTM, EPA) +/- 10%
  - Flow control maximizes accuracy by stabilizing flow pressure on sensor face and keep the diffusion rate into the sensor constant.
  - Use less Calibration gas - save money with 1 l/min. gas flow over. (Compared to no flow control at two & 3.5 liter/min. analyzers)
  - Use less NOx filter material with controlled flow
  - Constant gas flow independent of hose length or filter condition
  - Accurate measurements from – 120 inches up to + 20 inches H_2O
  - Longer hoses extension are easily added



In search of the perfect measurement - EC specific quirks

NO sensor – "bias" charge

- Need a stable and constant potential in the sensor, but due to materials used, it becomes slightly unstable
- To compensate a tiny electric current is applied to sensor at all times.
  - Runs down battery. Reason for dead battery.
- If the sensor looses stability the NO reading will be depressed – a few ppms to many more

Charge analyzer to restore sensor stability (2 – 24 hrs)

In search of the perfect measurement - NO_2 measurements

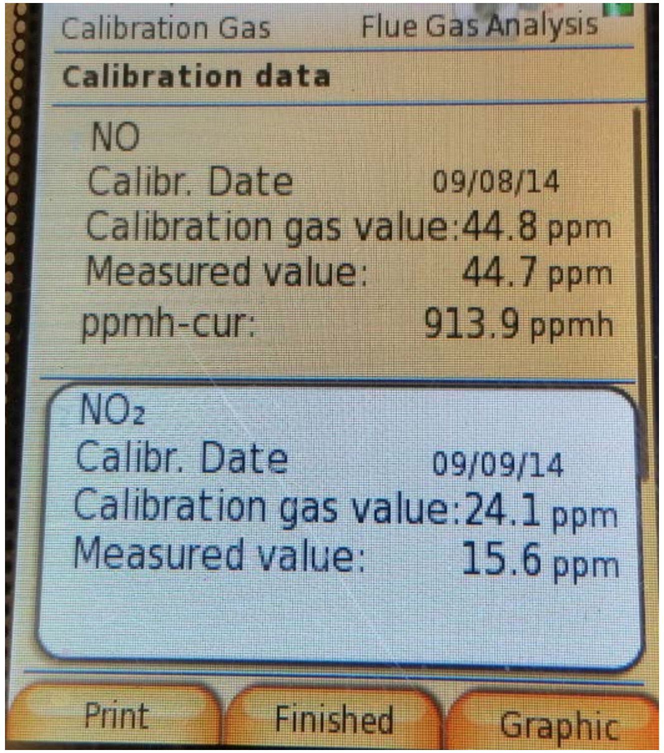
- Considered a very good, stable, reliable sensor. So why do reading sometime seem strange or show drift?

- NO2 is a very reactive gas
  - It's just sticky
  - It dissolves into moisture – just 12" inches of "wetted" hose can scrub up to 40%
  - Absorbs into rubber hoses, into sidewall particulate
  - Reacts with brass fittings or

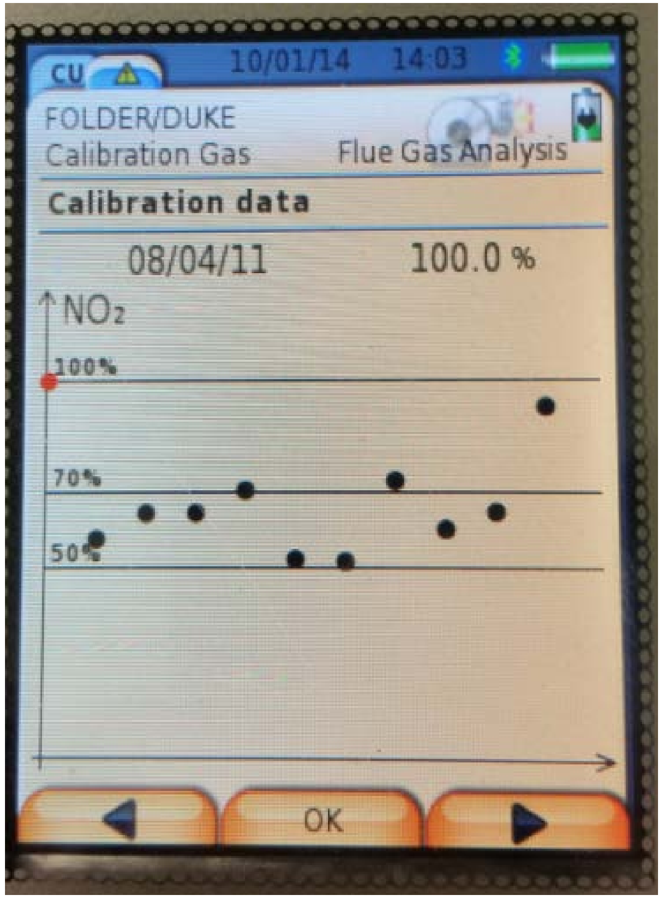
- It's not about sensor drift, but instead, sample transport, and…
- Good Calibration Gas is difficult to make.

NO_2 sensor – Identifying Calibration Problems

Check previous concentration before accepting new one



Check sensor output to confirm



Biggest problem - Not enough time to stabilize 5 min. minimum
Some analyzers hate this = results in "zero error diagnostics"

EC Sensor Quirk - Aging

- EC sensors use chemistry for operation. The chemistry simply wears out, the electrodes get consumed, BUT sensor remains linear.
- No substantial decrease in standard accuracy over one year. OK for tuning …maybe not OK for compliance testing.

Solution for Aging Sensors

- Talk loudly and repeat often…
- Try to exercise, take vitamins
- Just Calibrate or “Adjust” (use magnet, push button)
- Or Just replace sensors (diagnostic message or mV signal)
  - Newer developments - 3-year O_2, 6-year other sensors.

Linearity and EC Sensors

Linearis, a Latin word which means resembling a line.

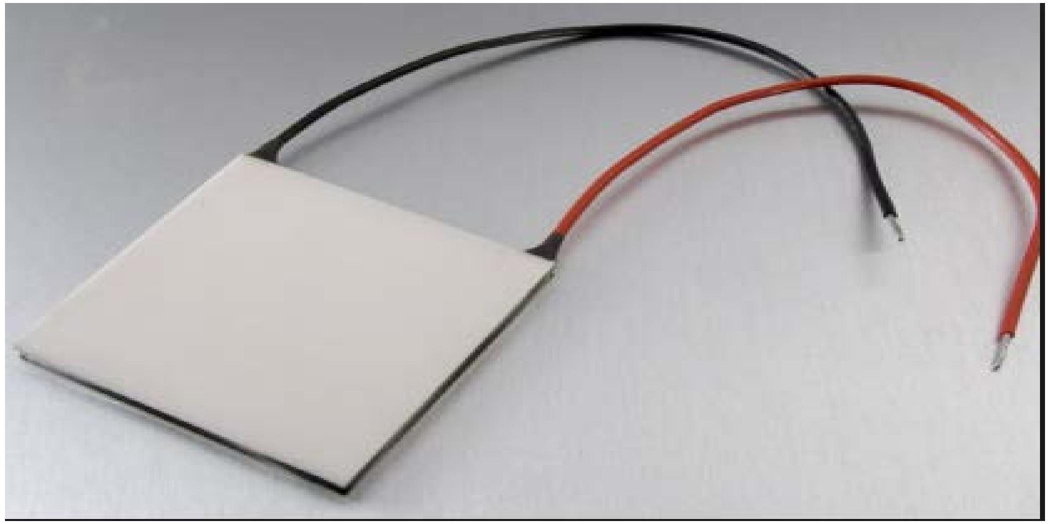
- For emission testing, linearity defines how well the analyzer responds across a specified operating range to approximate a straight line.
- Expressed as either linear or deviation from straight line –non linear
- EC sensor are inherently linear = Single point calibration vs. other technologies that require multi-point.
  - Note: you can use EC TO VERIFY Calibration gases

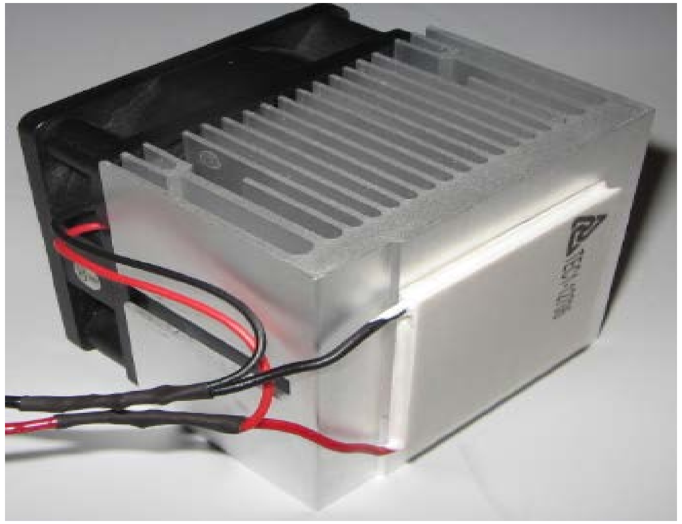
Other Sample Conditioning Considerations
Dry vs. Wet Basis Measurements

- Most permits require data on "Dry Basis".
  - Extractive sampling - Moisture is removed through sample conditioning system
- Wet Basis
  - Typically In-Situ, or across stack - CEMS
  - More common in Europe

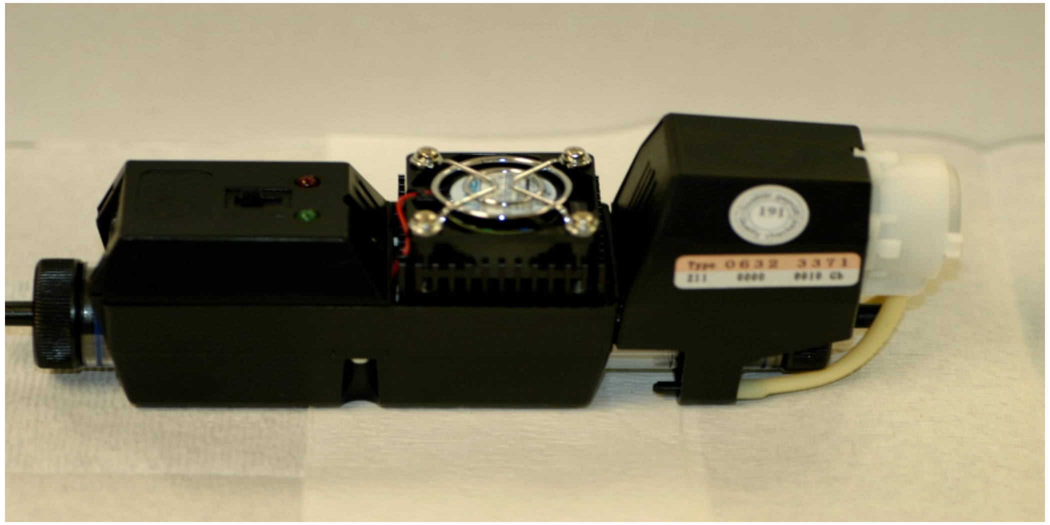

Drop Tube
NOT a good way to minimize error and increase accuracy…. but great way to scrub NO2 in lean burn.

Sample Conditioning





Peltier type



Sample Probes and Hoses

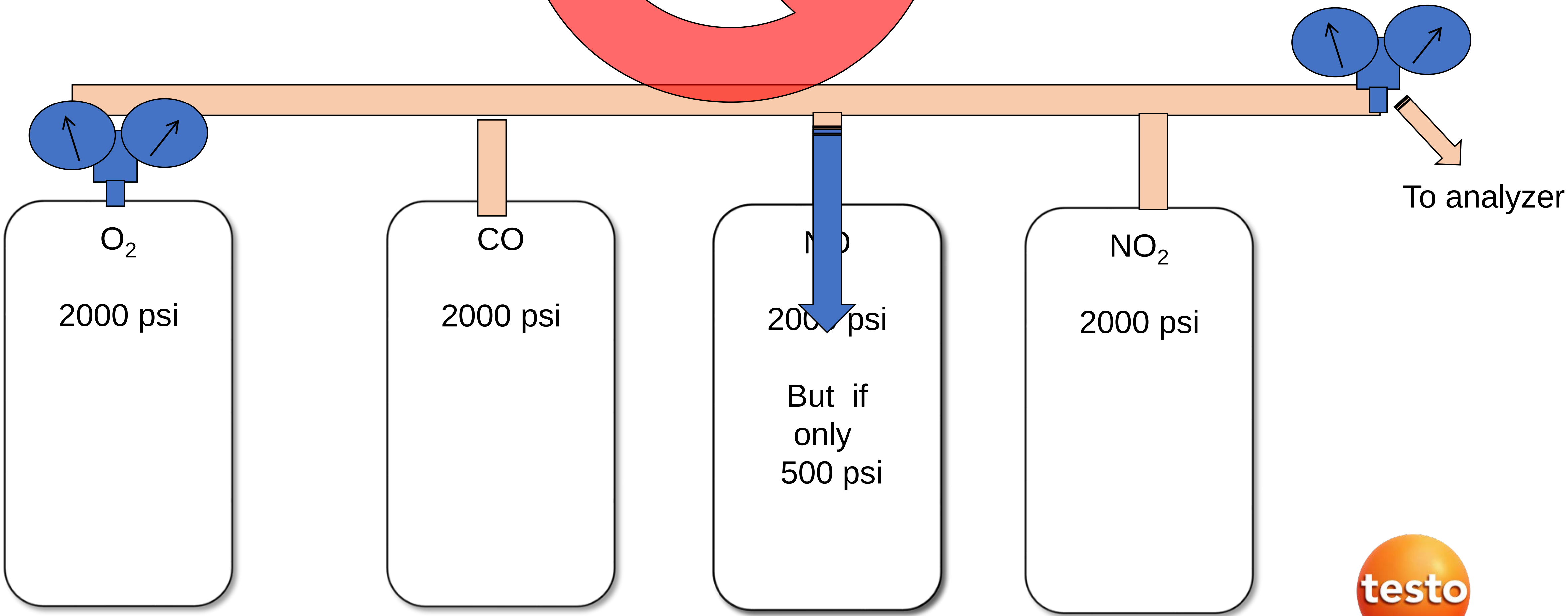
- Sample probes and hoses
  - Probes and sample lines are non-reactive.
    - stainless steel, Teflon®, or glass
  - All fittings are non-reactive
    - DO NOT USE - brass, rubber, Viton,
    - Pep Boy's or NAPA hose, schedule 40 pvc....
  - Use small diameter to minimize surface area and speed transport and analyzer response time
  - Using proper sample ports (straight run ducts)

Calibration Tips

- ***Patience!*** A good calibration cannot be rushed. The more stable the sensor response (when zeroed or spanned) the more accurate the calibration.
- Do a leak check when calibrating with CO and NO (balanced in nitrogen)
- Establish Asampling flow rate – Use this flow rate for all calibration and emission testing
- Look at entire analyzer response prior to calibrating. Check flow rate, make sure the balance concentration in bottle makes sense.
- Check NO_x cross interference on CO Sensor
  - Beads (scrubbing filter) Replace as needed when beads turn ash white or through calibration check or through electronic means)

Calibration hardware considerations

- Simpler is better – Always!
- Avoid large complex manifolds and check valves and brass fittings, then may look good and seem efficient but they can create unforeseen problems.



The Challenge for the Emission Tester

- ***Pre-knowledge*** - of regulations and complex testing procedures
- ***Pre-approved*** - testing protocol (could mean different protocols on same site)

On-site challenges

- Hope - unit is ready, it's operating correctly, and maintains the required testing load
- Must use accurate analyzer - passes the pre & post test calibration procedures
- Testing is done according to plan - and the unit will pass the test

Emission reporting challenges

- Data collection – complete, secure, backed-up, and compiled correctly
- ppm values are: corrected, converted, calculated, checked, and checked again
- Finally, the report is generated – in an acceptable format

Tester - Signs on the bottom line! (Designated felon)

Testing Tips

- Don’t hurry take your time and do not take shortcuts from protocol
- Allow Engine to reach steady state
- Pre-test the stack to get an idea of what to expect. Historical data is a great place to start
- Connect to stack start pre-sampling, establish flow rate
- Wake up sensors (specifically NO2 sensor)
- Check emissions to check cal gas bottles
- Check response time
- Warm up system before the actual test (20min)
- Zero sensors after warm-up period and get started.

ASTM D6522 note:

Stability and Linearity at analyzer – Not through sample lines

The Challenge of Emission Reporting

- ***Hundreds or even thousands of emission data points***
  - O2, CO, NO, NO2, temperature (sensors, stack, ambient) flow rate, etc.
- ***Data reduced down to single average values***
- ***Numerous calculations are used***
  - concentration corrections, pre & post drift corrections, span error corrections, etc.
- ***Excel is the "go-to" program for calculation*** (EPA method 19 example below)

NO_x at 15% O_2 = $(NO_x) \times [(20.9 - 15.0) / (20.9 - O_2)]$

$$C_{GAS} = (C_R - C_O)\frac{C_{MA}}{C_M - C_O}$$

NO_x Conc. = (ppm) x (molecular weight of NO_2 gas) x (Conv. Factor)

(molecular weight of NO_2 gas = 46 g/g-mole)

F_d-Factor (Fuel) = $\dfrac{1.00E06 \times (3.64\%H) + (1.53\%C) + (0.57\%S) + (0.14\%N) - (0.46\%O)}{GCV}$

$$\text{lb/MMBtu NOx} = (\text{ppm NOx}_{\text{corrected}})\,(1.19\text{x}10^{-7})\,(\text{F Factor}_{\text{Note 1}})\left(\frac{20.9}{20.9\text{-}\ O_2\%_{\text{corrected}}}\right)$$

$$\text{gm/hp-hr NOx} = (\text{ppm NOx}_{\text{corrected}})\,(1.19\text{x}10^{-7})\,(\text{F Factor}_{\text{Note 1}})\left(\frac{20.9}{20.9\text{-}O_2\%_{\text{corrected}}}\right)(\text{Specific Fuel Consumption}_{\text{Note 2}})\,(10^{6})\,(454)$$

$$\text{lb/hr NOx} = \frac{(\text{gm/hp-hr NOx})\,(\text{Engine Horsepower}_{\text{Note 3}})}{454}$$

Testo's Solution we've simplified the reporting process

TECsoft

Testing and Emission Compliance Software

- ***Compiles site information*** – combustion unit number, company, location, contact names, permit condition, fuel, etc.
- ***Records calibration data*** - pre & post calibration data or any other calibration procedure required (stability, linearity, etc.)
- ***Automatic testing programs*** – data log single or multi-run tests, shows real-time mass units, trending graphs, averages, etc.
- ***Generate Emission reports*** – Manages emission data and transfers data into final emission report (customized user-defined)

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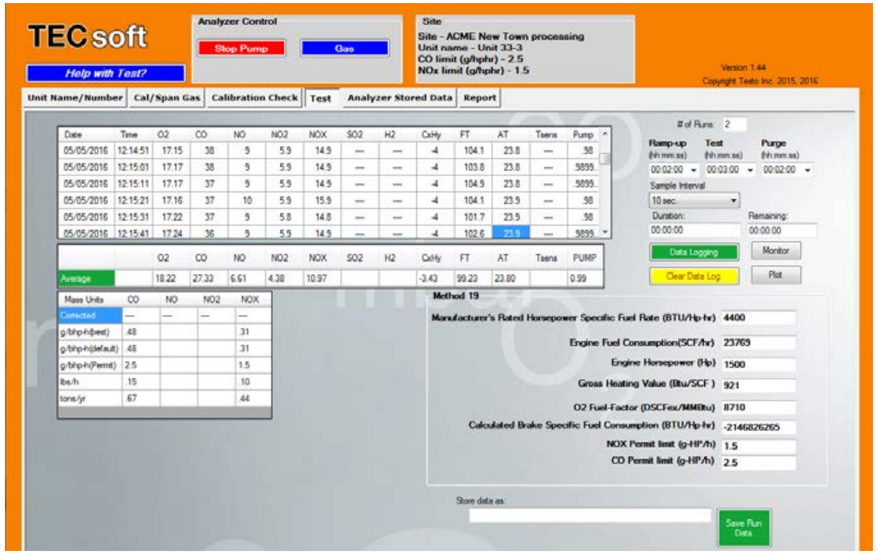
TECsoft How It Works

Unit Name/Number | Cal/Span Gas | Calibration Check | Test | Analyzer Stored Data | Report

Six tabs to navigate

Unit Name/Number	Choose the template that contains site information
Cal/Span Gas	Select the calibration gases
Calibration Check	Data log sensor response to calibration gas
Test	Start pump: a single test, multiple runs or user defined
Analyzer Stored Data	Download tests from analyzer
Report	Picking the calibration and test data file



1st Way to Minimize Measurement Variability

Manufacturing solutions - Analyzer designed to help eliminate measurement variability

Emission Grade Analyzers”

can minimize/eliminate measurement variability

Follow Manufacturer Specs for proper use of the analyzer“

The rest is up to you

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Questions?

- Flow Rate
- Peltier Chiller (Why do I need it?)
- What are the desiccants used for ?
- True NOx What is it?
- Do I need to calibrate at more than one point?

Thank you
for your attention.

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