DYNAMIC GAS STANDARDS FOR CALIBRATION
and Characterization of Electronic Nose Sensors

The use of Electronic nose (e-nose) systems to detect, classify, and in some cases quantify volatile organic compounds (VOCs) and other gases is increasing. An e-nose generally combines one or more chemical sensors to produce a characteristic response for a gas sample. E-nose systems have been investigated for applications including food quality, environmental monitoring, healthcare diagnostics, industrial monitoring, and security. A recent review describes e-noses as systems incorporating sensor arrays with controlled gas flow, data processing, and algorithms that help recognize and classify a distinctive gas mixture [1]. Although sensor technology continues to advance, the performance of an e-nose is dependent on the quality and precision of the chemical gas standards used to develop and evaluate it. Sensors must be calibrated with a known gas composition and concentration before their response is meaningful. Other important factors such as sampling techniques, differences in sensor technologies and materials, data processing, and changes in environmental conditions should be considered during calibration when analyzing e-nose performance.

> *"Sensors must be calibrated with a known gas composition and concentration before ..."*

The KIN-TEK FlexStream™ Permeation System provides a dynamic method for generating known gas challenges from Trace Source™ permeation devices available for over 550 different chemical gas standards. Controlled temperature and dilution gas flow provide NIST traceable concentrations of individual gas compounds or mixtures delivered directly to an e-nose or gas-sensor test chamber. Users can develop scenario testing to include exposure to baseline exposure, quantified dry VOC exposures, and controlled variable %RH exposures to effectively calibrate sensors for measured responses.

Why Controlled Gas Standards Matter for E-Nose Development

An e-nose does not automatically know the gases or concentration of the atmosphere presented to its sensor array. That relationship must be proven through various gas exposures at stated parameters and known concentrations. Singular or multiple Trace Source™ permeation tubes can be used to provide gas standards needed for e-nose development.

Exposing e-noses to the various scenarios provides data for developers to evaluate sensor characteristics including sensitivity, selectivity, repeatability, response time, linearity, operating range, and other important measurements when machine-learning or multivariate analysis is used.

During development, sensors may need to be exposed to:

- a blank or "Zero" carrier gas to establish baseline response,
- multiple concentrations of a target analyte such as a calibration curve,
- several chemically different analytes,
- potential interferents or contaminants, and
- controlled changes in environmental conditions such as humidity.

A MEMS-based VOC sensor study, for example, generated steady-state response trajectories by testing multiple gases at multiple concentrations and subsequently used machine-learning techniques to classify individual VOCs as well as binary mixtures [2]. A controlled gas-generation system therefore becomes part of the measurement foundation for creating meaningful sensor-response datasets.

The Challenge of Reproducibility

One of the continuing challenges in e-nose development is reproducibility between devices and between measurements. For example, Bruins et al. identified poor reproducibility among nominally equivalent e-noses as an important barrier to transferring calibration models from one device to another. Their work demonstrated that relatively small differences in metal-oxide sensor operating temperature significantly increased response heterogeneity [3]. Other e-nose literature also references sensor reproducibility, sensor drift, low-concentration sensitivity, and the lack of standardized data as barriers to broader alignment [1]. These challenges make it apparent that the chemicals presented to the sensor should be precisely controlled and repeatable. If gas concentration, flow, temperature, or humidity changes unintentionally between measurements, the resulting variation can become part of the sensor dataset and may affect the calibration.

Dynamic Gas Generation Using Permeation Tubes

A permeation tube provides a small continuous source of a pure chemical compound across a polymeric membrane. When maintained at a precisely controlled temperature, the analyte permeates through the device membrane at a quantified rate (emission rate) that is established via gravimetric weight loss. The emission rate is given as mass per unit time, commonly nanograms per minute (ng/min). The emitted analyte gas is combined with a controlled dilution gas flow to provide the resulting concentration, typically in ppm or lower ranges.

Once the permeation tube is stabilized at its operating temperature, different concentrations are produced by simply changing the total dilution flow. This makes using a permeation system particularly useful for sensor development because the same Trace Source™ permeation tube(s) can be used to generate a series of concentrations. Instead of changing from one premixed cylinder to another users simply: **Change the flow → change the concentration**, saving time, money and the struggle of working with gas cylinders. Sensors can therefore be calibrated with different concentrations while maintaining the same chemical source and by simply changing the dilution flow, often done in a matter of seconds.

FlexStream™ as an E-Nose Calibration Solution

The FlexStream™ Permeation System combines precise temperature control with highly accurate dilution gas flow control to dynamically generate a known vapor concentration from a Trace Source™ permeation tube. The modular approach of the FlexStream™ system allows users to start small and expand modules when their development testing dictates more complexity. For example, a basic configuration is: **FlexStream™ Base Module (Primary Dilution Capability) + Trace Source Tube(s) → Sensor Chamber = Calibration/Validation, ppm to ppb**.

For lower target concentrations, a secondary phase of dilution is used such as the **FlexStream™ Base Module (Primary Dilution) + Trace Source Tube(s) + Secondary Dilution Module → Sensor Chamber = Calibration/Validation at lower concentrations, ppm to pptr.**

This configuration has already been demonstrated in gas-sensor research where researchers at the University of Arizona and California Institute of Technology connected a FlexStream™ Gas Standard Generator to a sensor chamber for nitric oxide testing. The system generated NO from a permeation tube, mixed it with nitrogen or argon carrier gas, and used secondary dilution to generate extremely low concentrations for sensor evaluation [4]. The researchers measured the sensor response over a nitric oxide concentration range from 6.4 ppt to 240 ppt, purging the chamber with argon between exposures [4]. This illustrates one of the primary advantages of using a FlexStream™ permeation system to dynamically generate gas standards for sensor development.

Additionally, published sensor studies demonstrate the value of determining the response to a known gas standard concentration. In a recent SAW sensor study using KIN-TEK-generated gases, a concentration-response relationship for 2-CEES produced an R^2 value of 0.99289, demonstrating strong linearity between gas concentration and frequency response [5].

Evaluating Selectivity and Interferences

A useful e-nose must do more than respond to a gas. It must provide enough information to distinguish the target chemical signature from other compounds that may be present. A controlled test sequence may include a target gas with the exposure of different interferents in different scenarios. Resulting sensor response patterns would be compared to determine neural networks or other classification techniques. Recent e-nose research demonstrated sensor-response, response-time, and recovery-time parameters combined with PCA and support-vector-machine analysis to discriminate NO, H_2S, and mixtures of the two gases [1].

Similarly, MEMS multivariate sensor research has demonstrated classification of individual VOCs as well as binary VOC mixtures using machine-learning analysis [2]. For these experiments, accurately defining the chemical input helps separate sensor behavior from uncertainty in the test atmosphere.

Multi-Component Gas Standards and Chemical Fingerprints

Real-world odors and vapor samples are rarely composed of a single chemical. Food aromas, environmental odors, industrial process emissions, and human breath can contain numerous compounds at different concentrations. An e-nose is intended to recognize the combined pattern generated by these compounds rather than identify every individual component independently. Multiple compatible Trace Source™ permeation sources can be used to create controlled mixtures representing increasingly complex chemical challenges. Users can elect to develop sensors based on a general progression of using a single analyte to creating multicomponent mixtures for a specific "fingerprint". The expanded FlexStream™ system with the right modules provides the required solution for generating controlled training and validation datasets for pattern-recognition algorithms like that of breath analysis.

Breath analysis illustrates the importance of both complex mixtures and low concentrations. Human breath contains VOCs associated with metabolic processes and disease states. Sandia National Laboratories has summarized reported VOC signatures associated with respiratory infections, cancer, inflammatory conditions, and other diseases with example compounds including acetone, butanone, methanol, aldehydes, hydrocarbons, and organic acids [6]. Chemical-sensor arrays are attractive for these applications because they can potentially provide rapid and portable analysis. However, breath itself presents significant measurement challenges. Temperature, humidity, oxygen concentration, and carbon dioxide concentration differ substantially from ambient air and can alter the response of some sensor technologies [7]. Consequently, sensor development may require evaluation not only against different VOC concentrations but also under varying humidity and background conditions.

Humidity and temperature should be considered during e-nose characterization because both can influence sensor output. For example, many metal-oxide sensors exhibit humidity cross-sensitivity, with water vapor changing both baseline resistance and sensitivity [7].

Exposure to sensors using variable humidity in the testing phase was demonstrated by a 2025 Scientific Reports study of a SAW sensor for the chemical-warfare-agent simulant 2-CEES. Researchers used KIN-TEK gas sources and a FlexStream™ gas dilution system to control the known gas concentration and flow while independently varying temperature from −20 °C to 50 °C and relative humidity at 30%, 50%, and 70% [5]. Sensor performance was evaluated for selectivity, linearity, response/recovery time, repeatability, temperature dependence, and humidity dependence, noting a useful model for e-nose development because the chemical standards and environmental variables were deliberately controlled.

Advantages of the FlexStream™ + Trace Source™ Permeation Tube(s) Approach for Sensor Development

Freshly Generated Gas Standards
The test gas is generated dynamically from a permeation source rather than relying exclusively on a static and stored low-concentration mixture.

Multiple Concentrations from One Source
Changing dilution flow allows multiple concentration levels to be generated from a single permeation device.

Trace-Level Capability
Primary and secondary dilution capabilities can extend generated concentrations into very low ranges. The FlexStream™ has been used experimentally to deliver nitric oxide standards in the low-part-per-trillion range for advanced optical sensor research [4].

Controlled Multi-Analyte Testing
Multiple permeation sources held within multiple FlexStream™ modules can be used to create defined mixtures for selectivity, interference, and chemical-fingerprint studies.

Reproducible Sensor Challenges
Controlled temperature and flow provide defined experimental conditions that can be repeated during development, validation, and comparison of multiple sensors.

Broad Application Range with Broad Chemical Standard List of Over 550 Compounds
The list of gas standards offered in permeation tubes continues to grow with currently over 550 different analytes available. The same gas standard generation principle can support sensor development for a broad range of industries ranging from environmental monitoring, industrial safety, VOC detection, odor monitoring, food and beverage quality testing, breath research, toxic-gas detection, and chemical-threat detection, among others.

Conclusion

Electronic noses transform patterns of chemical-sensor responses into information about gases, vapors, and complex mixtures. Developing reliable e-nose performance therefore requires more than advanced sensors and sophisticated algorithms: it requires controlled and reproducible chemical gas standards to expose the sensor array to known concentrations while characterizing the response.

The KIN-TEK FlexStream™ Permeation System with the wide offering of Trace Source™ permeation tube(s) provides a flexible solution for generating known concentrations of gases and VOCs from NIST traceable certified gas sources. Concentrations can be changed dynamically through primary dilution or secondary dilution phases, multiple compounds can be combined for mixture studies, and environmental conditions can be controlled while the gas stream is delivered directly to a sensor chamber.

This capability allows researchers to systematically evaluate various conditions such as sensor sensitivity, selectivity, concentration response and response times, repeatability, and response to varying humidity as needed. Published research has already demonstrated the use of FlexStream™ systems for both ultra-trace nitric oxide sensor development and controlled SAW sensor evaluation under changing temperature and humidity conditions. For e-nose developers, the result is a direct connection between a known chemical input and the resulting sensor fingerprint—providing a controlled foundation for calibration, characterization, machine-learning development, and validation.

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Solve Your Trace Level Calibration Challenges with KIN-TEK Analytical, Inc. Trace Source™ Permeation Tubes and Systems

The Trace Source™ Permeation Tube technology is employed in KIN-TEK's Gas Standard Generators to provide accurate, NIST traceable calibration standards. KIN-TEK's products include a range of gas standard generators and permeation devices to fit almost any application that relies on the delivery of an accurate trace gas concentration. Individual gas generator modules can operate as stand-alone calibrators or be combined into a Gas Standard Generator System configured to solve the most complex applications. The System utilizes the FlexLink™ software that can log and export data for analysis and reference.

Contact a customer service representative now and discuss your specific application.

KIN-TEK Analytical, Inc. (KIN-TEK), is a leader and preferred provider of devices and instrumentation used for creating trace concentration calibration gas standards and complex gas mixtures. KIN-TEK revolutionized permeation tube technology in the 1970's and further developed the technology to produce Trace Source™ Disposable and Refillable Permeation Tubes. The Trace Source™ Permeation Tube is employed in KIN-TEK's Gas Standard Generators to provide accurate, on-demand calibration standards. Calibration gas standards are available for over 550 chemical compounds, each with a Certificate of Calibration for traceability to National Institute of Standards and Technology (NIST). KIN-TEK delivers trace gas calibration solutions and services worldwide for customer specific applications in the laboratory, field, and process industries!

KIN-TEK designs and builds calibration gas systems. KIN-TEK is committed to providing calibration gas standards that meet or exceed the expectations of our customers.

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