TDLAS technology for critical H_2S monitoring

Ensuring safety, compliance, and efficiency in natural gas pipelines

Endress+Hauser
People for Process Automation

This study presents experimental results demonstrating the capability of an Endress+Hauser TDLAS gas analyzer for monitoring H_2S in natural gas pipelines. The project included a year-long field trial of the analyzer installed at a natural gas company in the Midwestern United States.

Introduction

Hydrogen sulfide (H_2S) is a naturally occurring compound composed of one sulfur atom and two hydrogen atoms. It forms when bacteria break down organic matter and is commonly found in crude oil, natural gas deposits, and "biogas" produced by anaerobic digesters that convert organic materials into methane or biomethane.

H_2S is both highly corrosive and highly toxic. It can render certain steels brittle, leading to sulfide-stress cracking and damage to operational equipment. For this reason, natural gas producers, gas processors and pipeline operators continuously measure H_2S to protect infrastructure and comply with buyer specifications and applicable international, regional, and local regulatory limits. In many facilities, H_2S concentration is also used as a feedback parameter to control and optimize acid gas removal (sweetening) and sulfur recovery processes.

Also known as "sour gas" or "acid gas," H_2S is a colorless, extremely poisonous gas with an odor often described as "rotten eggs." It is detectable by most people at concentrations as low as 5 parts per billion (ppb), but becomes highly toxic and potentially fatal at levels above a few hundred parts per million by volume (ppmv). In raw natural gas and gas gathering fields, H_2S concentrations can be as low as 1 ppmv and as high as 20% in some regions. In biogas, H_2S can be as high as a few thousand ppmv. For "sales gas" in transmission and distribution pipelines, the maximum allowable concentration is 4 ppmv in the United States and around 5 mg/m^3 (~3.6 ppmv) in Europe and other regions, though operators typically maintain levels closer to 1-2 ppmv.

Why H_2S measurement matters

Accurate measurement of H_2S is essential throughout the natural gas value chain. Even small concentrations can present serious safety, operational, economic, and compliance risks. Key drivers for H_2S measurement include:

- **Personal safety –** H_2S is a toxic gas and can cause severe illness and/or death even at relatively low concentrations.
- **Corrosion protection –** H_2S contributes to corrosion and sulfide-stress cracking of pipelines and pressure-containing equipment, especially when moisture (H_2O) and carbon dioxide (CO_2) are present.
- **Feedstock quality and process reliability –** Excess H_2S can permanently poison refinery and petrochemical catalysts, causing costly downtime, decreased throughput, and premature catalyst replacement.
- **Contractual and regulatory compliance –**
  - In the United States, the Federal Energy Regulatory Commission (FERC) and Pipeline and Hazardous Materials Safety Administration (PHMSA) enforce safety and gas-quality standards within the U.S. Department of Transportation (DOT). Most U.S. custody transfer contracts specify a maximum of 4 ppmv H_2S.
  - Globally, many operators follow ISO 6326 (natural-gas–H_2S determination) and ISO 10715 (natural-gas sampling) as baseline international standards for measurement, sampling, and gas-quality control. These ISO frameworks support consistent H_2S-quality specifications across regions where national standards or energy-market regulations differ.

Concentration units for H_2S measurement

ppmv	Parts per million by volume (ppmv)
ppmw	Parts per million by weight (ppmw)
grains/100 sft^3	Grains per 100 standard cubic feet
percent	% of total gas

Conversion factors

1 grain/100 sft^3	~15.7 ppmv (depends on values used for standard conditions)
¼ grain/100 sft^3	~4 ppmv
10,000 ppmv	1%

Physical properties of H_2S

Boiling point	-76.60 °F (-60.3 °C)
Freezing point	-121.9 °F (-85.5 °C)
Molecular weight	34.08 g/mole
Specific gravity	1.1895
Lower explosive limit	4.0%

Danger levels of H_2

10 ppm	Unpleasant odor, safe for 8-hour exposure
100 ppm	Kills sense of smell in 3-15 minutes, stings eyes and throat
200 ppm	Rapidly kills sense of smell, severely stings eyes and throat
500 ppm	Immediate dizziness, breathing ceases in a few minutes
700 ppm	Quick unconsciousness, death if not immediately rescued

Field trial objectives

Field trials are performed under an agreement between the equipment supplier and an end user prior to the release of a newly developed product. In this case, the equipment was designed and manufactured in Rancho Cucamonga, California USA by Endress+Hauser, a global provider of measurement devices for the Oil & Gas, Chemical, Power & Energy, and other process industries. The end user was a utility that provides natural gas and electricity to millions of residents in the Midwestern United States.

Both parties engaged in the field trial with significant investment in time and expense on both sides.

For Endress+Hauser, detecting and resolving issues prior to offering a device globally is extremely important, especially for complex systems such as laser-based gas analyzers. The manufacturer's objectives were to:
- Test the new product under real field conditions
- Identify any unknown issues and bugs
- Verify the expected measurement performance in field conditions
- Obtain real-time feedback on the overall design, installation, operation, and software from experienced users

Gas companies invest in the deployment of H_2S gas analyzers to ensure the safety of the public and pipeline infrastructure. For this field trial, the gas company's objectives were to:
- Understand the technology used to measure H_2S
- Build expertise within the engineering and technical support staff
- To install, commission, operate, maintain and decommission the devices in the field

Cybersecurity goals

Cybersecurity and testing protocols are also critical in ensuring the safety and operational integrity of pipeline control systems and security equipment before deployment. In 2021, hackers launched a ransomware attack on Colonial Pipeline—one of the largest refined oil pipelines in the United States—prompted the Transportation Security Administration (TSA) to implement new cybersecurity requirements. The TSA Security Directive (SD) outlines procedures and requirements for testing equipment before it is introduced into a production environment.

API Standard 1164 (3rd edition), developed from TSA's cybersecurity requirements, provides guidelines for managing cyber risks in industrial automation and control (IAC) environments to ensure security, integrity, and resiliency. When testing equipment prior to the production deployment, API 1164 emphasizes:

1. **Isolation and segregation:** IAC environments must be properly isolated from non-IAC environments to maintain operational continuity and reduce cybersecurity threats.
2. **Risk-based approach:** Cybersecurity requirements should be tailored to company's risk management processes, ensuring alignment with mission, objectives, and risk strategy.
3. **Testing and validation:** Equipment must undergo thorough testing and validation to ensure secure operation within the IAC environment and to prevent the introduction of vulnerabilities.
4. **Continuous monitoring and improvement:** A management system must be in place to continuously monitor and improve cybersecurity posture through regular assessments and updates.

By following these guidelines, companies ensure that equipment is secure and resilient before being introduced into the production environment, thereby protecting critical infrastructure and maintaining operational integrity. Additionally, participating in a field trial provides the end user with early exposure to a future product, potential influence on design and usability, and hands-on experience with the user-interface, operation and diagnostics – particularly valuable for complex technologies that require deeper expertise.

Figure 1: Example of a typical natural gas well (one of dozens in a typical storage field)

Operation details

The site's operation as a midstream natural gas facility with underground storage, gas processing and gas distribution was an excellent representation of the midstream industry and included many key elements found in similar sites worldwide. The operation involves gas injection into the storage field during warm weather and gas delivery during cold weather, which presents certain measurement challenges. Inclement weather is also a factor at this site, making it a suitable location to test new equipment designed to work in harsh environmental conditions.

Test site overview

The compression station is situated within a large field of underground storage wells. These wells are used to inject gas into the porous rock formations during summer months and to extract gas during high-demand winter months. The wells are connected by underground pipelines routed to the compression station. The primary function of the compression station is to compress and maintain the pressure of natural gas to ensure its efficient and continuous flow through the pipeline system.

Before compression, the gas must be treated. Liquids must be separated, and the gas must be dehydrated to prevent internal corrosion or hydrate formation.

Figure 2: Example of a natural gas compression station

Figure 3: (Left) Heated sampling probe; (Center) pressure-reduction system; (Right) sample-distribution enclosure mounted outside the analyzer shed

The compression station does not include facilities for H_2S removal (gas sweetening), but operators must still control H_2S levels in the natural gas. To do this, the station measures H_2S concentrations both when gas is injected into the storage fields and when it is extracted for delivery.

Safety is the highest priority. In addition, strict tariff regulations must be followed. "Tariffs" are contractually mandated measurements performed at custody transfer points to ensure the gas meets defined quality standards. These gas-quality standards specify maximum allowable concentrations of contaminants. A natural gas tariff is a comprehensive document outlining the rules governing gas transportation and storage, including limits on permissible H_2S concentrations. In the U.S., these contracts are regulated by FERC and monitored by PHMSA under the DOT. In Europe, pipeline specifications are defined under EN 16726 for natural gas and EN 16723 for biomethane.

By monitoring gas entering and exiting the storage field, operators can maintain proper H_2S control.
Historically, storage fields have experienced H_2S spikes (from natural reservoirs or upstream producers).
Monitoring H_2S at the station is therefore critical to prevent H_2S incursion into the storage fields since the station lacks gas-sweetening capabilities.

H_2S analyzer installation and setup

A heated sampling probe with an integrated liquid rejection membrane was used to extract gas from the pipeline at approximately 600 psig (41 barg). The sample was transported through heated stainless-steel tubing to prevent condensation. A heated pressure-reduction system lowered the sample pressure to roughly 50 psig (340 kPa) while maintaining the sample above its dewpoint.

From there, a low-pressure line – also heat-traced – carried the conditioned gas approximately 100 feet (30 m) to the analyzer shed. The sample line terminated in a small distribution enclosure mounted outside the shed, where the sample was routed to multiple analyzers.

Inside the analyzer shed (approximately 12 x 12 feet or 4 x 4 m), several gas analyzers were installed, including the Endress+Hauser JT33 and SS2100 H_2S analyzers, along with instruments for H_2O, O_2, and gas-composition measurements. Sample lines were distributed directly to each analyzer, and all instruments vented into a common exhaust line routed outdoors.

Figure 4: (Left) The Endress+Hauser JT33 TDLAS H_2S analyzer positioned beside the Endress+Hauser SS2100 TDLAS H_2S analyzer; (Right) front view of the JT33 TDLAS gas analyzer with a small control enclosure mounted above it

A small control enclosure mounted above the JT33 housed a cellular modem used to transmit diagnostic and operational data from the JT33 to Endress+Hauser during the trial. This modem received Modbus data from the JT33, which enabled factory specialists to monitor H_2S concentration and analyzer health, install firmware updates, and adjust configuration settings. During remote-access periods, the JT33 remained fully isolated from the gas company's internal network. When necessary, operators provided time-stamped reference data from the SS2100 and the site's gas chromatograph for comparison. Both analyzers were validated using certified binary calibration gas.

TDLAS analyzer technology

The JT33 employs tunable diode laser absorption spectroscopy (TDLAS). The tunable diode laser operates in the near-infrared (NIR) region (around 1.5 micrometers for H_2S measurements). Its wavelength is precisely controlled by adjusting the laser current while maintaining a stable temperature. Sweeping the input current generates a wavelength scan. The laser beam passes through the gas sample and reaches a detector, and the analyzer records the absorption of light during each scan. Multiple scans occur every second. The resulting spectrum covers a narrow wavelength region selected to capture the strongest H_2S spectral features, while minimizing interference from background components such as methane and ethane).

In the simplified spectrometer illustration below, the laser beam passes through the sample, reflects off a flat mirror, and returns to the detector. This arrangement allows the laser, detector, thermoelectric cooler, and pressure / temperature sensors to be housed together inside a compact enclosure with all electrical connections on one side.

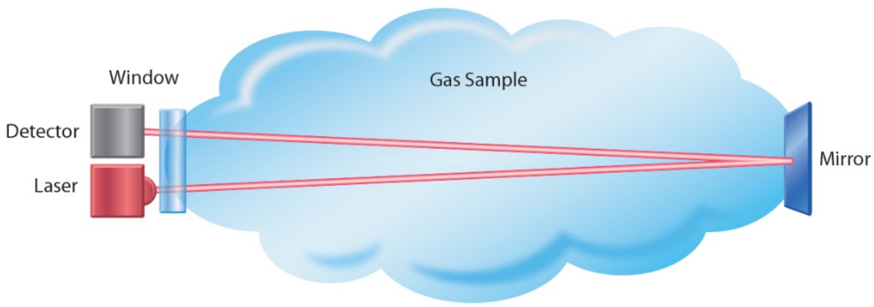

Figure 5: Simplified diagram of TDLAS spectrometer. In this architecture, there is one flat mirror, and the laser passes through the sample twice, increasing its effective path length to about 1 meter.

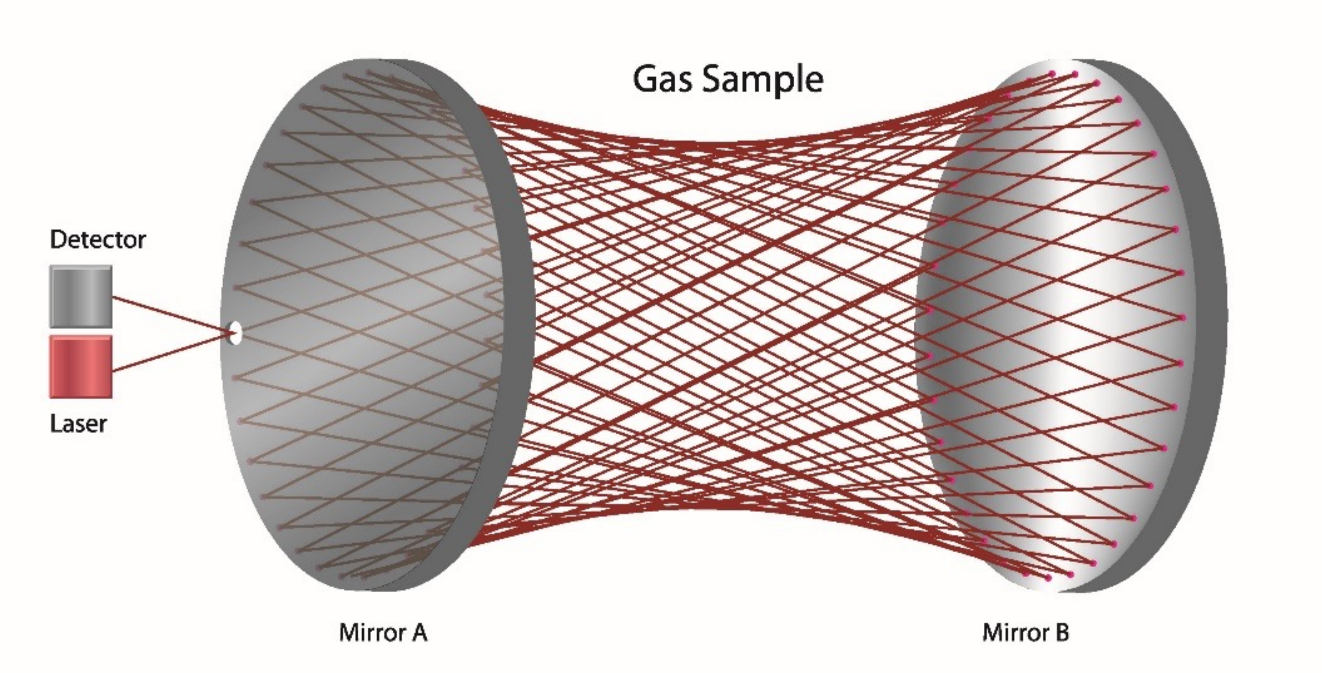

Figure 6: Simplified diagram of TDLAS spectrometer using a multi-pass Herriott cell. The architecture uses two aspherical mirrors, allowing the laser to pass through the sample multiple times and extend the effective path length to approximately 28 meters.

The optical path length directly influences measurement sensitivity – the longer the beam interaction with target molecules in the sample, the higher the absorption.

- ~0.1 m for percent-level concentrations
- ~1 m for single-digit ppm to hundreds of ppm
- ~10+ m for sub-ppb or tens-of-ppb detection.

For this study, the path length was 28 meters long to achieve sub-ppm repeatability and accuracy, single-digit ppm concentrations, and a lower detection limit (LDL) around 200 ppbv. In natural gas applications, where H_2S levels commonly fall between 1-2 ppmv and alarms are set at 3-4 ppmv, a long-path multi-pass optical cell is used. In a typical Herriott-cell configuration, shown below, two aspherical mirrors guide the laser beam through the sample many times, creating an effective path length of several tens of meters. The design is mechanically robust, tolerant to vibration, and field-serviceable; mirrors can be cleaned or replaced without requiring ultra-high reflectivity coatings. Some reflectivity can be lost over time without impacting the measurement, and if the mirrors do become contaminated, they can be cleaned or replaced in the field.

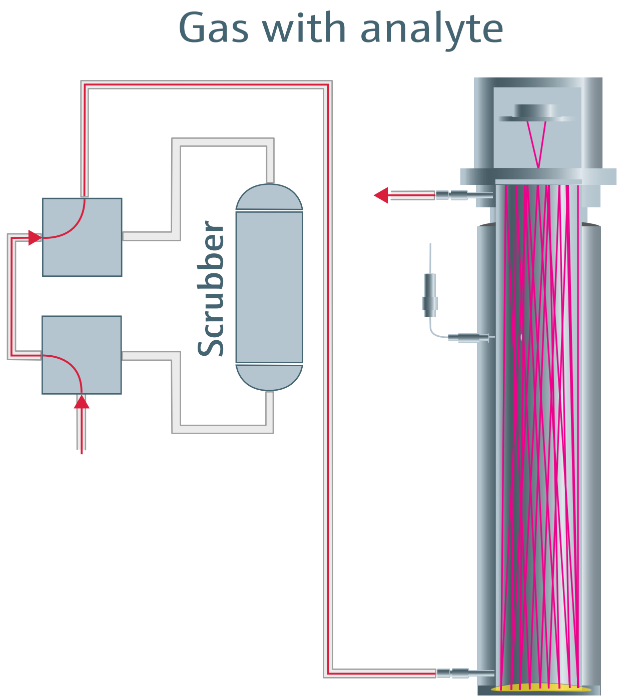

Figure 7: The figures above depict the two stages of differential spectroscopy. On the left, the sample passes through the scrubber to capture the baseline spectrum (gas without analyte). On the right, the scrubber is bypassed, and the full spectrum is captured (gas with analyte).

Differential TDLAS technology

Differential TDLAS technology is also coupled with multi-pass cells for H_2S measurement in natural gas. Because the H_2S spectral features are relatively weak compared to the broader hydrocarbon and CO_2 baseline, and because background composition can vary, the baseline spectrum can shift over time. By using differential TDLAS technology, the baseline spectrum is effectively removed, making the measurement very stable over long periods of time (many years).

Differential TDLAS technology works by subtracting the baseline spectrum from the full spectrum. The baseline spectrum is obtained by selectively removing the analyte (H_2S) using a highly selective scrubber. In the first stage, the gas is directed through the scrubber with solenoid-operated valves, which removes all H_2S from the sample. This scrubbed gas then enters the multi-pass cell, allowing the analyzer to capture the baseline spectrum.

In the second stage, the scrubber is bypassed, and the analyzer records the full spectrum with H_2S present. Multiple times per second, the analyzer acquires both spectra, subtracts the baseline from the full spectrum, and generates a clean H_2S-only spectrum. The H_2S concentration is then determined from the resulting spectral features.

In all of these configurations, the spectrometer operates at atmospheric pressure. A sample must therefore be extracted from the pipeline, transported to the analyzer, and vented after analysis. This process is handled by a sample conditioning system (SCS), whose main purpose is to filter out entrained liquids and particulate matter and to regulate sample pressure and flow. The wetted components are typically electropolished 316 stainless steel, and trapped volumes are minimized to avoid delays in sample transport.

A bypass flow is typically incorporated to sweep the inlet side of filters and reduce maintenance frequency. This results in two flow paths: one through the analyzer (filtered gas) and one bypassing the analyzer (unfiltered gas). Both streams eventually combine and are vented to atmosphere or flare.

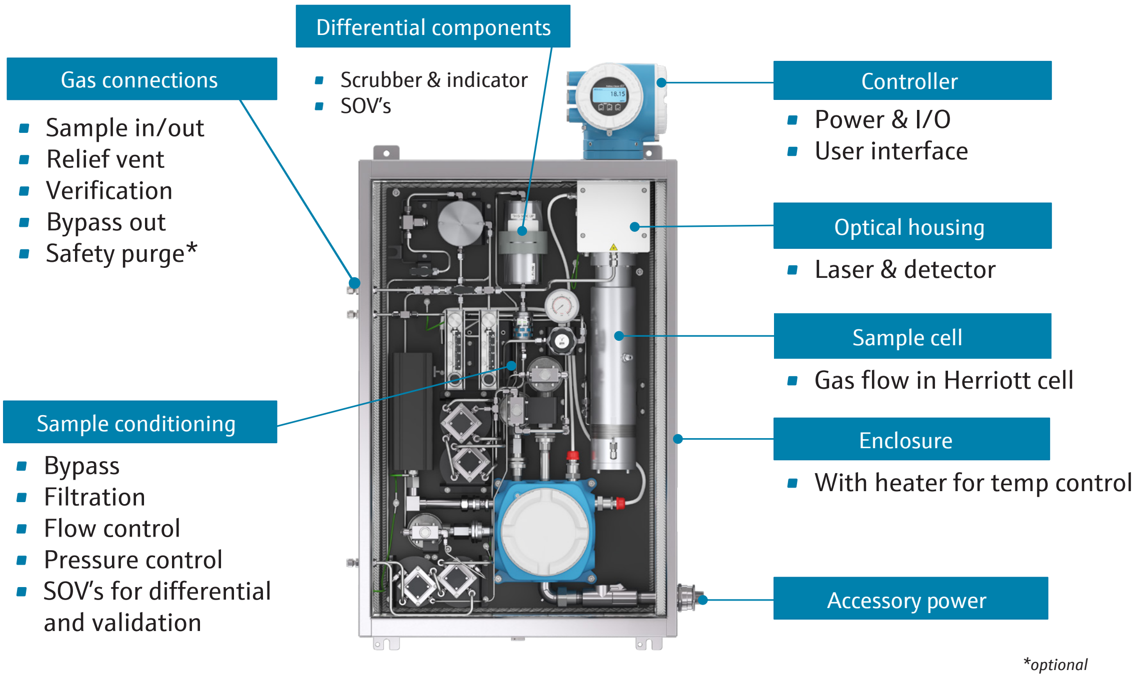

Figure 8: The main components of the JT33 H_2S analyzer are shown. The spectrometer cell and controller (upper right) are positioned alongside the differential switching system. The system includes the sample-conditioning components, the internal heating and temperature-control elements, and a two-point auto-validation system.

JT33 TDLAS gas analyzer design

The JT33 analyzer diagram below shows the arrangement of the spectrometer and the sample-system components described in the previous section. The JT33 also includes an optional "auto-validation" feature that allows end users to connect a reference gas bottle and periodically validate the analyzer.

Comparison between predecessor and successor analyzers

The JT33 H_2S analyzer was released to the market in 2024, superseding the Endress+Hauser's earlier SS2100 H_2S analyzer introduced in 2008. While the core spectroscopic measurement principle remains fundamentally the same, the JT33 incorporates more than 15 years of technological advancement – particularly in algorithms and spectroscopic techniques – to address field-observed challenges and enhance overall robustness.

Beyond these foundational improvements, the JT33 includes several modernized platform features that were not available on the SS2100. These enhancements improve usability, connectivity, diagnostics, and field reliability. The JT33 now supports more hazardous-area classifications, higher ingress-protection ratings, an integrated web server for configuration and monitoring, on-board data logging, Heartbeat Technology® for continuous verification, and native Modbus TCP communication. Together, these updates elevate the analyzer's operational resilience and simplify lifecycle support.

The JT33 also utilizes an all-digital platform with significantly improved signal-to-noise performance compared to the SS2100, which relied on older analog circuitry for components such as the temperature controller and laser driver. These improvements result in better measurement stability, more consistent performance, and expanded application capability. For example, the JT33 allows end users to store and select multiple calibration files and core spectral settings can be dynamically adjusted based on programmed conditions.

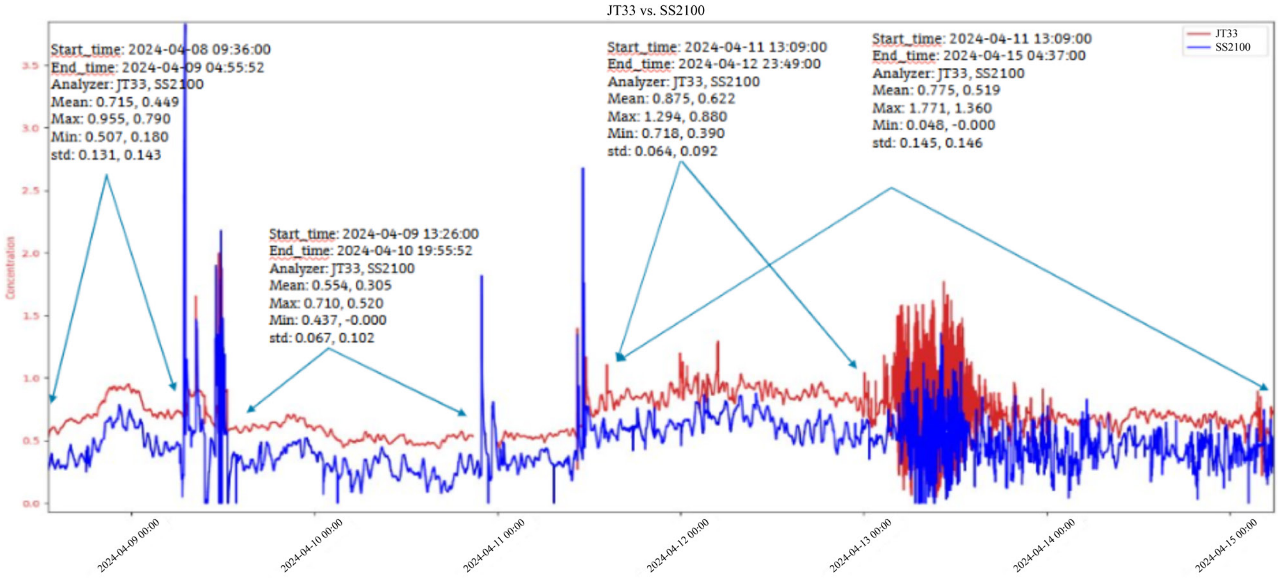

Figure 9: Comparison of H_2S readings from the JT33 (red) and SS2100 (blue)

Results

Figure 9 above represents several days of comparison data between the JT33 analyzer (red trace) and the SS2100 analyzer (blue trace). The traces differed by approximately 250 ppbv – within specifications – and the JT33 demonstrated better repeatability and lower noise than the SS2100. Periodic spikes appearing in the SS2100 data were traced to variations in CO_2 and ethane concentrations. After reviewing the JT33 spectral data, corrections were applied to the CO_2 and C_2 reference settings in the SS2100, resolving the issue. This serves as a good example of how remote monitoring of spectral data can support troubleshooting and improve analyzer performance.

Finally, Figure 10 illustrates a series of anomalous spikes in the 4–20 mA output signal caused by a software bug triggered under specific spectral conditions within the JT33 analyzer electronics. These spikes resulted in false positive H_2S readings. The issue was observed in real time by the factory team through remote monitoring, enabling rapid diagnosis. A software patch was developed and deployed via a firmware update, resolving the problem. This incident highlights both the value of real-time remote access and the importance of field trials for identifying and correcting issues prior to commercial release.

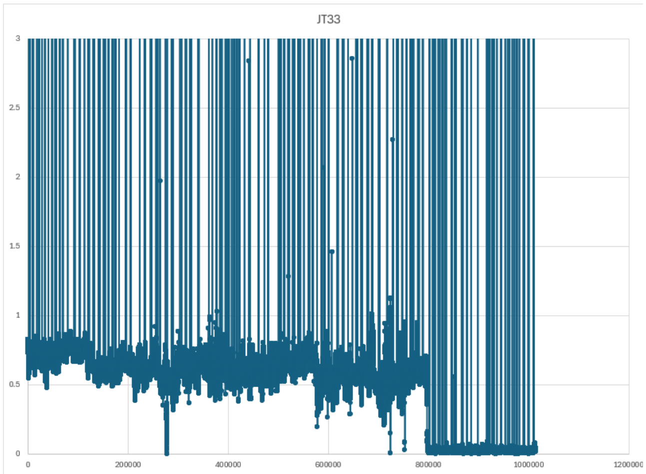

Figure 10: Transient spikes in the 4–20 mA output

Conclusion

The JT33 field trial served as an important validation of the analyzer's performance in a regulated environment, where safety, reliability, and data integrity are paramount. Over the course of a full year, the JT33 analyzer was exposed to the operational realities of a live natural gas facility, providing a rigorous test of its capabilities in continuous H_2S measurement.

Compared to the previous SS2100 analyzer platform, the JT33 introduced a step-change in both measurement stability and operational simplicity. The advancements resulted in more consistent data quality and fewer operational disruptions.

The field trial also highlighted the effectiveness of remote collaboration. Teams from multiple locations were able to work together through secure remote access to monitor performance, troubleshoot issues, and implement configuration updates in real time. This distributed-support model not only accelerated problem resolution but also demonstrated a scalable approach to analyzer deployment and lifecycle management.

Overall, the trial outcomes clearly illustrate the technical soundness and operational readiness of Endress+Hauser's JT33 TDLAS H_2S analyzer. Its measurement performance, combined with the remote connectivity infrastructure that enables real-time support, positions the JT33 as a compelling solution for critical H_2S monitoring applications. It is particularly well suited for environments where safety, compliance, and efficiency must be maintained.

The findings from the field trial have since been validated across commercial installations in natural gas production, storage, custody transfer, renewable natural gas (RNG), carbon capture (CCUS), refining, and other process gas applications. These deployments have confirmed the JT33's ability to maintain reliable performance under varying process conditions and operating environments.

Benefits of the JT33 TDLAS analyzer system:

- Reliable H_2S measurement ensures continuous gas delivery for natural gas pipeline operators, biomethane producers, and carbon capture plant owners through continuous, real-time monitoring that prevents pipeline corrosion and minimizes the risk of uncontrolled events
- Proven differential measurement technology tolerates contaminants and accommodates stream changes, ensuring dependable measurements that meet and document specification field requirements
- High analyzer availability and low maintenance requirements combined with easy field serviceability significantly reduce operational costs
- Advanced diagnostics and measurement algorithms, supported by Heartbeat Technology, enable reliable automation of gas quality control and downloadable verification reports

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