

# **API Standard 556-4: Instrumentation, Control and Protective Functions for Gas-Fired Heaters – Flue Gas Analyzers, 1<sup>st</sup> Edition**

**API Standard 556-4  
1st Edition**

**Ballot Draft**

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## Introduction

API 556 is transitioning from a single document to a multipart series of documents, each issued as a first edition.

The subtitles for the eight parts are listed below.

- Part 1: Instrumentation
- Part 2: Control
- Part 3: Protective Functions
- Part 4: Flue Gas Analyzers
- Part 5: Main Burner Ignition Criteria
- Part 6: Tube Skin Thermocouples
- Part 7: Overlay for Oil-Fired Heaters (reserved for future publication)
- Part 8: Overlay for Steam Methane Reforming Furnaces (reserved for future publication)

This document is the fourth part of API Standard 556, Instrumentation, Control, and Protective Functions for Gas-Fired Heaters. API 556-4 contains requirements for flue gas analyzers used for fired heaters that:

- a) are designed in accordance with API 560;
- b) contain burners which are designed and tested in accordance with API 535;
- c) have instrumentation, controls, and protective functions in accordance with the respective parts of API 556.

In API Standards, the SI system of units is used. In this standard, where practical, US Customary (USC) units are included in brackets for information.

A bullet (O) at the beginning of a clause or sub-clause indicates that either a decision is required, or further information is to be provided by the purchaser. This information should be indicated on the purchaser's checklist (see Annex x) or stated in the inquiry or purchase order.

## Background and Rationale

This standard provides a performance-based work process for selecting flue gas analyzer technology for fired heater applications. The process evaluates the worst-case fuel gas disturbance, characterized by the magnitude and rate of change in air demand, to define the application requirements for maintaining the fired heater within operational limits.

Analyzer technology is selected by comparing the time constant of the fuel gas disturbance with the overall system response time (OSRT) to determine whether the analyzer system can meet the performance requirements. This approach allows either close-coupled extractive or laser-based measurement to be selected based on the specific application. Adequate response time alone does not ensure a useful measurement; the ability to obtain a representative flue gas sample from the specific firebox is equally important. Integrating analyzer selection and placement into the front-end fired heater design process allows mounting, connections, and associated service requirements to be addressed early, helping to reduce or eliminate field changes after delivery.

By providing timely, representative measurements, the selected analyzer system improves the ability of the O<sub>2</sub> trim controller to maintain the fired heater within operational limits, reducing demand frequency on low-O<sub>2</sub> or high-CO/combustibles overrides to the fuel gas controller and operator response to alarms.

Analyzer diagnostics support condition-informed maintenance in lieu of reliance on fixed calibration intervals, enabling timely intervention, reducing unnecessary maintenance, and improving analyzer system reliability and availability.

## 1 Scope

API 556-4 specifies requirements and provides recommendations for the selection and application of flue gas analyzers to fired heaters in general refinery and petrochemical service.

### 1.1 Inclusions

This Standard applies to flue gas analyzers installed in fired heaters that are built in accordance with API 560 and that have a project authorization date that occurred on or after the publication date of this standard.

### 1.2 Exclusions

This standard does not apply to Continuous Emission Monitoring Systems (CEMS). Information for CEMS analysis can be found in API 555 and site-specific requirements should be discussed with the local regulatory agency.

**NOTE** With the exclusion of CEMS, all flue gas measurements within the context of this document are reported as a wet basis measurement rather than a dry basis measurement.

## 2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Standard 560, *Fired Heaters for General Refinery Service*

## 3 Terms, Definitions, and Abbreviations

### 3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

#### 3.1.1

##### **air demand**

In the context of combustion processes, a variation in the amount of air required to achieve complete combustion of a fuel.

**NOTE** Air demand is often correlated with a change in flue gas oxygen content, as oxygen levels in the flue gas indicate how much excess air is present after combustion.

#### 3.1.2

##### **analyzer system response time**

The time required for a step change in flue gas composition at the point of measurement to be reported at 63% or 90% (i.e., T63 or T90) of the final value at the signal output terminal of the flue gas analyzer (i.e., wired to the BPCS or logic solver).

**NOTE 1** For a close-coupled extractive analyzer, the analyzer system response time includes the lag time associated with all installed components (e.g., integral flame arrestor, internal volume of the sample probe, probe filter, aspirator air pressure). The operator will typically consider these potential differences when comparing published response times.

**NOTE 2** Unless the response time is published as either T63 or T90 response to a process step change, the published value may be the sensor's response to calibration gas and may not accurately reflect the analyzer system response time. Alternatively, T63 or T90 response to a process step change may be available from the vendor upon request (e.g., with or without integral flame arrestors or sample probe).

### **3.1.3**

#### **Basic Process Control System (BPCS)**

A computer-based implementation of the control functions necessary to operate and manage a specific process unit or area.

NOTE 1 The BPCS includes field instrumentation, communications between field devices and the control processors, HMIs, and any other computers and communications required to support or report upon process performance.

NOTE 2 The BPCS does not include general-purpose business computers and networks, desktop workstations, or other computing resources not used exclusively to operate, configure, or maintain a process unit or area.

NOTE 3 Protective functions are considered to be independent from the BPCS functions but can share communication network components, engineering tools, and HMI.

### **3.1.4**

#### **bridgewall**

The location where the flue gas exits the radiant section and enters the convection section.

### **3.1.5**

#### **calibration gas**

A mixture of gases with a known composition that is used to calibrate and maintain the accuracy of gas detectors and analyzers.

### **3.1.6**

#### **calibration**

A maintenance procedure during which calibration gas is applied to the analyzer and the corresponding signal output is adjusted, if required, to keep the deviation between the measured and reported values within the supplier's specified tolerance.

### **3.1.7**

#### **close-coupled extractive analyzer**

A point-based analyzer directly mounted to the fired heater flange which uses an aspirator to extract a continuous sample to a heated sensing element within the enclosure that measures the concentration of one or more components before returning the sample to the flue gas.

NOTE The analyzer sensor enclosure is typically heated and insulated to ensure the sample gas stays above the dewpoint.

### **3.1.8**

#### **combustibles**

Specifically referring to carbon monoxide and hydrogen within the flue gas as products of incomplete combustion.

NOTE 1 For refinery fuel gas (RFG) containing hydrocarbons, a miniscule concentration of carbon monoxide, typically in ppm, is expected even with excess air, i.e., fuel-lean combustion. This condition is because carbon monoxide combustion is controlled by hydroxyl radicals in the flame front, not by direct oxidation.

NOTE 2 A combustibles analyzer (catalytic bead) will typically detect CO, hydrogen, and other combustibles (excluding methane). Since the methane molecule cracks at a higher temperature, a separate catalytic detector is required to measure methane and other hydrocarbon molecules that exhibit similar catalytic cracking behavior. Thus, the term "combustibles" can be easily misinterpreted and subsequently misapplied.

### **3.1.9**

#### **combustibles or COe sensor**

A heated, multi-element detector that measures non-speciated combustibles, as defined above, in the flue gas stream.

NOTE 1 Combustibles is a vernacular that has evolved in development of catalytic detectors that use a blend of carbon monoxide and hydrogen for calibration.

NOTE 2 CO equivalent (COe) is a vernacular that has evolved in development of catalytic detectors that specifically use carbon monoxide for calibration.

NOTE 3 This sensor's measurement range is typically configured in parts per million (ppm) by controlling the temperature in a range to maximize sensitivity (e.g., 225-305 °C / 437-581 °F).

### **3.1.10 complete combustion**

An ideal condition that occurs when all the hydrocarbon fuel reacts completely with the oxygen to produce only carbon dioxide and water or when a pure hydrogen fuel reacts completely with the oxygen to produce only water.

### **3.1.11 dry basis measurement**

A method of analysis that reports analytical results based on the condition of the sample being free of any condensable compounds, including moisture.

### **3.1.12 excess air**

Amount of air above the stoichiometric requirement for complete combustion.

NOTE 1 Excess air is expressed as a percentage.

NOTE 2 Heater operating efficiency is frequently associated with percent oxygen in the flue gas. Percent excess air and percent oxygen are related but not interchangeable. For example, 15% excess air typically corresponds to approximately 3% oxygen in the flue gas. The actual relationship varies with fuel composition.

### **3.1.13 fabricator**

The party that provides the facilities and services to physically construct all or part of the project work as directed by the supplier.

NOTE The fabricator is typically responsible for the quality control of their own work and quality assurance of any directly purchased or sub-contracted work by them.

### **3.1.14 flue gas analyzer**

A device that reports the concentration of one or more components in the flue gas stream of a fired heater.

### **3.1.15 gross oxygen analysis**

A measurement which reports the amount of oxygen in the flue gas independent of any unburned fuel or combustibles.

NOTE 1 Gross oxygen is also known as total oxygen.

NOTE 2 When combustibles or unburned hydrocarbons are present, a gross oxygen analyzer will report a higher value than net oxygen analysis.

NOTE 3 When no combustibles or unburned hydrocarbons are present, a gross oxygen analyzer will essentially report the same value as net oxygen analysis.

### **3.1.16**

#### **incomplete combustion**

A condition that occurs when fuel gas does not react completely with oxygen in air due to imperfect mixing at the burners or fuel-rich combustion.

NOTE 1 For typical onset of incomplete combustion, the leading indicator is combustibles (i.e., carbon monoxide and hydrogen) followed by unburned hydrocarbons, typically methane, in the flue gas stream from incomplete RFG combustion. In limited cases, methane may be detected concurrently, including during initial burner light-off when the fired heater temperature is very low, well below the autoignition temperatures (AITs) of hydrogen and hydrocarbons, and during equipment failure when the fuel-air mixture becomes very fuel-rich, including flameout conditions.

NOTE 2 For clarification on catalytic combustibles and methane sensors, see the definition of “combustibles”, Note 2.

### **3.1.17**

#### **methane / hydrocarbon sensor**

A heated, multi-element detector that measures methane and other hydrocarbon molecules that exhibit similar catalytic cracking behavior.

NOTE 1 Since the methane molecule cracks at a higher temperature, a separate catalytic detector is required to measure methane and other hydrocarbon molecules that exhibit similar catalytic cracking behavior.

NOTE 2 This sensor's measurement range is typically configured in percent.

NOTE 3 Combustibles in the ppm range will also burn on the sensor but the indication will be negligible.

### **3.1.18**

#### **net oxygen analysis**

A measurement which reports the remaining oxygen at the heated sensor after all unburned fuel or combustibles are consumed.

NOTE 1 Net oxygen is also known as excess or residual oxygen.

NOTE 2 When combustibles or unburned hydrocarbons are present, a net oxygen analyzer will report a lower and more conservative value than gross oxygen analysis.

NOTE 3 When no combustibles or unburned hydrocarbons are present, a net oxygen analyzer will essentially report same value as gross oxygen analysis.

### **3.1.19**

#### **overall system response time**

The time required for the flue gas analyzer to reach 63.2% of its final value in response to a step change in heat release at the burners, which includes the radiant section time constant and the analyzer system response time.

NOTE 1 While the analyzer system response time may benchmark T90 published values, the control systems engineer will typically use the first order time constant (e.g., T63) for control loop tuning purposes.

NOTE 2 For a ZrO<sub>2</sub> sensor, there is a difference in response time to increasing versus decreasing oxygen. To keep the fired heater within operational limits, the sensor response to a step change decrease in oxygen in the flue gas is prioritized for control loop tuning purposes.

### **3.1.20**

#### **owner purchaser**

The party with responsibility for all or part of the process and thermal design / definition, the mechanical specification, procurement, and construction / installation of the purchased equipment.

NOTE 1 The owner or purchaser may work through an engineering contractor (contractor) as an agent undertaking owner's requirement for the engineering, procurement, and construction phases of work, including representation of the owner on decisions related to operation and maintenance as may be required. The term "purchaser" within this document will be considered synonymous with the term "contractor" or "owner."

NOTE 2 The owner is responsible for operation of the process and equipment and is synonymous with the term operator as referenced in the standard.

### **3.1.21**

#### **path-averaged analyzer**

An instrument mounted directly to the fired heater that measures the concentration of specific gases in a path across a section of the fired heater.

### **3.1.22**

#### **point-based analyzer**

An instrument mounted directly to the fired heater that measures the concentration of components in the flue gas at a specific point within the fired heater.

NOTE This instrument may be a close-coupled extractive or laser-based probe analyzer.

### **3.1.23**

#### **Quantum Cascade Laser (QCL) Absorption Spectroscopy**

A method of analysis using a laser source operating in the mid-infrared region for detection of a specific component in the flue gas.

### **3.1.24**

#### **radiant section time constant**

With the fired heater operating at design absorbed duty, the time required for the oxygen content in the flue gas at the top of the radiant section to reach 63.2% of its final value in response to a step change in heat release at the burners.

NOTE The oxygen trim controller can be modeled as a first order lag process.

### **3.1.25**

#### **reference gas**

A gas used for the reference side of ZrO<sub>2</sub> sensors, typically instrument grade air with ~20.9% O<sub>2</sub> content.

### **3.1.26**

#### **supplier**

The party that manufactures or supplies equipment and services to perform the duties specified by the purchaser.

NOTE The supplier typically has the prime responsibility for the thermal design, detailed engineering, material procurement, project management and manufacturing processes involved in the physical supply of the fired equipment including all aspects of quality assurance, quality control for work of their own and others whom they qualify for providing work, products, or services on their behalf i.e. vendors, fabricators, refractory manufacturers, and refractory contractors.

### **3.1.27**

#### **tramp air**

Any air that enters the fired heater except through an operating burner.

### **3.1.28**

#### **Tunable Diode Laser (TDL) Absorption Spectroscopy**

A method of analysis using a laser source operating in the near-infrared region for detection and reporting specific components (i.e., O<sub>2</sub>, CO, or CH<sub>4</sub>) in the flue gas.

### **3.1.29**

#### **validation**

A maintenance procedure during which a calibration gas standard is applied to the analyzer and the corresponding signal output is not adjusted.

### **3.1.30**

#### **vendor**

The party that provides engineered products, sub-components, or services for the project work.

**NOTE** The vendor, whether they directly produce the materials or are agents in supply of such components, have responsibility for the quality of the product to either recognized industry or other standards as directed by the purchaser. Vendors typically supply sub-components such as; burners, fans, dampers, instrumentation, pipe hangers, castings, refractory, pipe / tubes, fittings, etc. A vendor may also provide specialty engineering services such as finite element analysis (FEA). Within the context of this standard, the supplier has prime responsibility for the products and services provided by the vendor.

### **3.1.31**

#### **wet basis measurement**

A method of analysis that reports analytical results based on all components in the sample, including moisture.

### **3.1.32**

#### **zirconium oxide (ZrO<sub>2</sub>) sensor**

A heated electrochemical cell that generates a millivolt output in response to the difference between the flue gas oxygen concentration and the reference oxygen concentration, typically ambient air or instrument air.

**NOTE** Using the Nernst equation, the magnitude of the millivolt output is inversely proportional to the logarithm of the ratio of the oxygen concentrations on the two sides of the sensor.

## **3.2 Abbreviations**

For the purposes of this document, the following abbreviations apply:

- |         |                                 |
|---------|---------------------------------|
| 1) BPCS | basic process control system    |
| 2) HMI  | human machine interface         |
| 3) LDL  | lower detection limit           |
| 4) LEL  | lower explosive limit           |
| 5) QCL  | quantum cascade laser           |
| 6) RFG  | refinery fuel gas               |
| 7) RTD  | resistance temperature detector |
| 8) SIS  | safety instrumented system      |
| 9) TDL  | tunable diode laser             |
| 10) TFI | trial for ignition              |

## 4 Overview

**4.1** For new fired heaters built in accordance with API 560, API 556-4 prescribes the measurement of both oxygen and carbon monoxide / combustibles in the flue gas.

**NOTE** The availability of both oxygen and combustibles measurements can improve the basis for establishing actionable operating limits. Where low-oxygen limits are established primarily from oxygen measurements and operating experience, carbon monoxide / combustibles measurements provide additional confirmation of the onset of incomplete combustion. This information can support more informed determination of constraint-control limits and low-oxygen alarm setpoints. For additional clarification, see API 556-2 and API 556-3.

**4.2** Depending on the selected technology, flue gas analyzers can measure oxygen, carbon monoxide, combustibles, hydrocarbons, methane, or a combination thereof and are typically either close-coupled extractive or laser-based.

**4.3** Flue gas analyzers are part of the control system strategy to monitor combustion efficiency and to keep the fired heater within operational limits. Examples include:

- 1) oxygen trim controller;
- 2) carbon monoxide / combustibles trim controller;
- 3) low oxygen and high combustibles override to the fuel gas controller;
- 4) operator response to BPCS alarm.

**4.4** Where applicable, protective functions may utilize flue gas analyzers to take corrective action when the fired heater exceeds operational limits. Examples include:

- 1) low oxygen trip;
- 2) high carbon monoxide / combustibles trip.

**4.5** Important considerations when selecting a flue gas analyzer for a specific fired heater application include:

- 1) the capability to establish a representative sample;
- 2) the magnitude and rate of change of the fuel gas disturbance;
- 3) the overall system response time of the analyzer technology under consideration relative to the first-order time constant (T63) of the fuel gas disturbance.

**NOTE 1** Refer to API 556-2 for the application of flue gas analyzers to process control.

**NOTE 2** Refer to API 556-3 for the application of flue gas analyzers to protective functions.

**NOTE 3** Refer to API 560 for guidelines regarding connections for point-based or path-averaged measurement (e.g., the number, size, location and spacing of analyzer flange connections, distance above platform, etc.).

## 5 Work Process

### 5.1 Estimate the Change in Air Demand for a Change in Heat Release at the Burners

**5.1.1** The purchaser shall specify the maximum variability in fuel gas supply pressure, temperature, and composition (e.g., P, T, and MW) and the associated change in air demand (e.g., percent change in flue gas oxygen) to define the application requirements for maintaining the fired heater within operational limits. The change in air demand should represent the worst-case boundary condition and may be determined using historical data or a calculated basis.

**NOTE 1** Fuel gas disturbance data is used to support analyzer selection and is not intended to define control system design or tuning.

**NOTE 2** The change in air demand may be calculated using a step change in heat release at the burners while holding air flow constant, representing the selected worst-case boundary condition for changes in fuel gas composition, pressure, or temperature. Alternatively, historical GC-based data (e.g., 90/10 percentile) may be used to define upper

and lower limits of fuel gas variability. Trending the flue gas O<sub>2</sub> response to these boundary conditions provides an empirical estimate of the rate of change in air demand. The resulting first-order time constant (T63) characterizes the fuel gas disturbance timescale, which is compared to the overall system response time to support selection of the appropriate flue gas analyzer technology.

**5.1.2** When evaluating variability in the fuel gas supply, both the magnitude and rate of change shall be considered.

**5.1.2.1** The magnitude of change informs the selection of fuel flow measurement (volume or mass), the percent oxygen setpoint, and the potential addition of a fuel gas heating value analyzer (e.g., energy flow control). Compared with compensated volume flow measurement, mass flow measurement additionally accounts for changes in MW and may be used to further reduce the burden on the O<sub>2</sub> trim controller when changes in air demand would otherwise approach or exceed the available excess air in the flue gas. For additional guidance, see API 556-1.

NOTE 1 Fuel gas mass flow measurement accounts for changes in MW, providing a leading indication of changes in fuel gas heating value and the associated change in air demand. The flue gas analyzer measurement provides a lagging indication due to the overall analyzer system response time.

NOTE 2 Significant variability in fuel gas inert content can limit the benefit of mass flow control because changes in inert content contribute to mass flow without contributing to heating value. Hydrogen concentrations above approximately 70% can also result in a mass flow penalty, potentially producing greater O<sub>2</sub> variability than volume flow or burner pressure control. Where either of these conditions exist, energy flow measurement and control may be warranted. For additional clarification, see API 556-1.

**5.1.2.2** The rate of change, as defined by the fuel gas boundary condition, informs the selection of flue gas analyzer technology by comparing the fuel gas disturbance T63 to the overall system response time.

**5.1.3** The fuel gas disturbance T63 and overall system response time should be sufficiently separated to maintain an approximate first-order response of the oxygen measurement under the defined boundary condition. Where sufficient separation cannot be achieved with a close-coupled extractive analyzer, a faster analyzer technology (e.g., laser-based measurement) should be considered.

**5.1.3.1** To maintain an approximate first-order response, the overall system response time of the oxygen measurement should be at least 3 to 4 times faster (i.e., have a time constant 3 to 4 times smaller) than the fuel gas disturbance T63 for laser analyzers and 4 to 5 times faster for close-coupled extractive analyzers.

NOTE This separation of time constants increases the likelihood that the oxygen trim controller can maintain the fired heater within operational limits during normal trim operation and fuel gas override when approaching operating limits.

**5.1.3.2** When applying active carbon monoxide control, laser-based analyzer technology with an analyzer system response time of 2 to 5 seconds is recommended.

NOTE For close-coupled extractive analyzers, combustibles response times are typically on the order of 15 seconds (T63), which limits their applicability for active CO control during rapid disturbances.

## **5.2 Select a Flue Gas Analyzer to meet the Application Requirements**

**5.2.1** As a result of the above analysis, the estimated magnitude of change and rate of change in air demand due to a step change in heat release at the burners impacts the selection of the applied technology.

**5.2.2** Flue gas analyzers are a lagging indicator on the process hazard timeline. If the rate of change in air demand can challenge a close-coupled extractive analyzer to keep the fired heater within operational limits, select laser-based technology. If the magnitude of change in air demand can challenge either type of flue gas analyzer to keep the fired heater within operational limits, select mass fuel flow or energy flow control to reduce the burden on the oxygen trim controller. While mass fuel flow and a fuel gas heating value analyzer are primarily used to reduce the magnitude of change in air demand, both are leading indicators on the process hazard timeline which may further reduce the rate of change burden on the oxygen trim controller. For more information, refer to API 556-1.

**5.2.3** Selecting a flue gas analyzer that meets the application's performance requirements increases the capability of the oxygen trim controller to keep the fired heater within operational limits and reduces the

demand frequency on the BPCS low oxygen override to the fuel gas controller, operator response to alarm, and SIS trip (i.e., where applicable). If the magnitude of change or rate of change in air demand outpaces the oxygen trim controller, potential consequences are control loop instability and substoichiometric combustion.

NOTE 1 API 556-2 recommends constraint controls to keep the fired heater within operational limits. This reduces the alarm frequency for operator response and the trip frequency of protective functions. Selecting a flue gas analyzer that meets the application's performance requirements is a critical step to achieving this design objective.

NOTE 2 A design consideration for reducing the burden on the oxygen trim controller and maintaining the fired heater within operational limits is to increase the % O<sub>2</sub> setpoint. However, for a given fired duty, this reduces the CO<sub>2</sub> concentration in the flue gas due to dilution from excess air, lowers combustion efficiency, increases total CO<sub>2</sub> emissions (mass flow), and can increase NO<sub>x</sub> formation.

### **5.3 Select Analyzer Placement**

**5.3.1** Flue gas analyzer connection location and quantity shall be per API 560, Section 15.

**5.3.2** Flue gas analyzer shall be direct mounted (i.e., not remote mounted).

**5.3.3** Purchaser shall specify whether the analyzer(s) will be located at the top of the radiant section, the base of the convection section, or the inlet of the stack beneath the stack damper.

NOTE When selecting either point-based or path-averaged technology, there are unique challenges (e.g. pros and cons) to be resolved. If point-based measurement is preferred, multiple locations (i.e., mounting flanges and sensors) may be required for large fired heaters to meet the application requirements (see B.5). If path-averaged measurement is preferred, the mounting pad and flange will have vendor specific requirements to maintain acceptable nozzle alignment and reduce the effects of fired heater flexure. Additionally, when temperature compensating laser-based measurement with an external input, it is important to locate the temperature measurement in proximity (e.g., within 1 m / 3 ft, refer to API 560) to the flue gas measurement to reduce the offset between actual flue gas temperature and reported flue gas temperature (i.e., due to radiated temperature loss near process tubes). For additional clarification, see 7.2.3.

**5.3.4** The following are considerations when choosing the location for the flue gas analyzers:

1) Radiant section outlet / base of convection section

a) Pros

- i) Measures the oxygen / carbon monoxide / combustibles in the flue gas before entering the convection section. Combustibles entering the convection section, with sufficient quantity and temperature (e.g., above 610 °C / 1130 °F for carbon monoxide), can potentially result in afterburning within the convection section.
- ii) Removes the convection section as a source of tramp air that impacts the oxygen indication. Tramp air can occur in any opening (tube penetrations, out of service burners, observation ports, header boxes, etc.).

b) Cons

- i) More challenging to obtain a representative oxygen / carbon monoxide / combustible indication due to the differences in fired heater geometry, burners in service and recirculation patterns within the radiant section.
- ii) Requires extra attention to mounting to reduce the impact of fired heater flexure with a longer path length.
- iii) More challenging to obtain a representative flue gas temperature indication due to interference from process tube radiated heat.

2) Inlet of the stack

a) Pros

- i) Flue gas flow is more turbulent and better mixed when exiting the convection section over the operating range of the fired heater.
- ii) Requires less attention to mounting to reduce the impact of stack flexure with shorter path length.
- iii) Less challenging to obtain a representative flue gas temperature indication.

b) Cons

- i) If afterburn occurs in the convection section, the carbon monoxide / combustibles will report lower than what is present in the radiant section outlet.
- ii) If not properly sealed, tramp air introduced in the convection section will have a higher oxygen indication than in the radiant section outlet.

#### **5.4 Front End Load the Fired Heater Design Process**

While API 560 and API 556-4 are well aligned for flue gas analyzer applications, all design requirements (e.g., the number and location of flanged mounting connections and the associated service platforms) may not be fully addressed. Selecting the flue gas analyzer technology and specifying the mounting and service requirements as early as possible (i.e., before the bidding process) will reduce or eliminate field changes after delivery.

### **6 Design Requirements**

#### **6.1 Measurement Requirements**

**6.1.1** Oxygen and combustibles shall be measured with either close-coupled extractive or laser-based technology that meets the response time requirements.

**NOTE** Laser-based analyzers may be used to detect carbon monoxide when the hydrogen concentration in the fuel gas is less than 80 vol %. If hydrogen concentration in the fuel gas is greater than or equal to 80 vol %, these analyzers may be used with approval from the analyzer vendor. While current laser-based technology cannot detect hydrogen in the flue gas at temperatures that exist in a fired heater, emerging technology may permit measuring hydrogen in the future. Hydrogen concentration less than 80 vol % assumes enough hydrocarbons are present in the fuel gas to generate and allow detection of carbon monoxide as a product of incomplete combustion.

**6.1.2** Purchaser shall specify whether methane measurement is required as part of the analyzer system. Where methane measurement is used as part of a post-purge, pre-ignition permissive the selected methane threshold shall be compatible with the demonstrated capability of the applied methane measurement technology (e.g., catalytic bead or laser-based). For clarification, see B.7.

**NOTE 1** During startup operation, methane measurement may be used as a post-purge, pre-ignition permissive to verify that flammable gas concentrations have been reduced to an acceptable level prior to introducing an ignition source.

**NOTE 2** In normal operation, methane may be present in the flue gas during partial loss of flame. For typical refinery fuel gas, methane will be present during total loss of flame.

#### **6.2 Analyzer System Response Time Requirements**

**6.2.1** For laser-based analyzers, the analyzer system response to a flue gas composition step change shall be less than 5 seconds for oxygen, carbon monoxide, and methane.

**6.2.2** For close-coupled extractive analyzers with integral flame arrestors as prescribed in 7.3.1.3, the analyzer system response to a flue gas composition step change at commissioning (i.e., not calibration gas introduced at the sensor behind diffusers or flame arrestors) shall be:

- Less than 15 seconds to T90 for oxygen
- Less than 25 seconds to T90 for combustibles
- Less than 25 seconds to T90 for methane

**NOTE 1** While the analyzer system response time may benchmark T90 published values, the control systems engineer will typically use the first order time constant (e.g., T63) for control loop tuning purposes.

**NOTE 2** In-situ ZrO<sub>2</sub> sensors with flame arrestors, as specified in this standard, do not meet the response time requirements.

**NOTE 3** Close-coupled extractive analyzer system response times are based upon vendor specified sample flow with a newly commissioned clean system (e.g., clean sample tubing, sample filters, and flame arrestors).

**6.2.3** If the close-coupled extractive analyzer system response time degrades to twice that of a newly commissioned clean system, corrective action should be taken. Response time degradation may be detected using a low sample flow alarm or time verification testing as noted in B.1.

### **6.3 Overall System Response Time Considerations**

**6.3.1** The fuel gas analysis described in 5.1 defines the disturbance timescale (T63) associated with the boundary condition. This disturbance timescale is compared to the overall system response time, which includes both the radiant section time constant and the analyzer system response time, to support selection of the appropriate flue gas analyzer technology. Maintaining adequate separation between the disturbance timescale and the overall system response time supports effective response of the oxygen trim controller during normal operation and upset conditions.

**6.3.2** At design absorbed duty, the radiant section of a fired heater typically exhibits a time constant of approximately 15 seconds, increasing to approximately 45 seconds at turndown, as illustrated in Tables 1 and 2. These values are representative, and the actual radiant section time constant depends on heater geometry and fired duty. When the analyzer system response time is small relative to the radiant section time constant, the overall system response is primarily governed by the heater dynamics, allowing the oxygen measurement to approximate first-order behavior. In contrast, when the analyzer system response time becomes comparable to the radiant section time constant, the oxygen measurement reflects the combined effect of both time constants, requiring greater separation from the fuel gas disturbance T63 to maintain approximate first-order behavior.

**6.3.3** Sufficient separation between the fuel gas disturbance T63 and the overall system response time is required to achieve an approximate first-order response of the oxygen measurement. The time constant separation multiplier provides an effective means of achieving this separation. Accordingly, two practical regimes apply for analyzer selection. For laser-based analyzers, which typically have analyzer system response times on the order of 2 to 5 seconds, the analyzer is well separated from the radiant section time constant, and a time constant separation multiplier of approximately 3 to 4 is generally sufficient. For close-coupled extractive analyzers, the analyzer system response time can be comparable to the radiant section time constant, and a greater time constant separation multiplier of approximately 4 to 5 is generally sufficient to maintain the fired heater within operational limits.

NOTE 1 The time constant separation multiplier represents the separation between the fuel gas disturbance timescale (T63) and the overall system response time, recognizing that the analyzer contributes a fixed response lag while the radiant section time constant varies with firing rate.

NOTE 2 The time constant separation multiplier depends on the relative magnitude of analyzer system response time and radiant section time constant and may be expressed by the ratio  $T_a/T_r$ . When  $T_a/T_r$  is less than approximately 0.33, the radiant section dominates and a multiplier of approximately 3 is typically sufficient. As  $T_a/T_r$  increases toward approximately 0.67, analyzer response becomes more influential and a multiplier of approximately 4 is typically sufficient. When  $T_a/T_r$  exceeds approximately 0.67, analyzer response materially affects the overall system response, and a multiplier of approximately 5 is typically sufficient. These ranges are approximate and interpreted using engineering judgment based on the specific application.

NOTE 3 The overall system response time represents the combined effect of the radiant section time constant and the analyzer system response time, including additional delays introduced by components such as flame arrestors, sample tubing, and filters. These effects may increase under operating conditions (e.g., due to fouling) and are reflected in the representative values used for analyzer selection.

| HEATER OPERATING AT DESIGN ABSORBED DUTY                                                                                                           |                                                         |                                                     |                                                     |             |                                          |                                     |                                                            |           |
|----------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------|-------------|------------------------------------------|-------------------------------------|------------------------------------------------------------|-----------|
| LASER-BASED ANALYZER (NO SAMPLE SYSTEM)                                                                                                            |                                                         |                                                     |                                                     |             |                                          |                                     |                                                            |           |
| Sensor Type                                                                                                                                        | Published Analyzer System Response (sec)                | Ta = Typical Rolling Average (sec)                  | Tr = Sample Radiant Section Time Constant T63 (sec) | Ratio Ta/Tr | Overall System Response Time Ta+Tr (sec) | Time Constant Separation Multiplier | Minimum Fuel Gas Disturbance Timescale T63 (sec) T63 (min) |           |
| TDL                                                                                                                                                | 2 to 5                                                  | 5                                                   | 15                                                  | 0.33        | 20                                       | 3                                   | ≥ 60                                                       | ≥ 1.00    |
| CLOSE-COUPLED EXTRACTIVE ANALYZER WITH CLEAN SYSTEM<br>(e.g., clean sample tubing, sample filters, and flame arrestors)                            |                                                         |                                                     |                                                     |             |                                          |                                     |                                                            |           |
| Sensor Type                                                                                                                                        | Ta = Published/Estimated Analyzer System Response (sec) | Tr = Sample Radiant Section Time Constant T63 (sec) |                                                     | Ratio Ta/Tr | Overall System Response Time Ta+Tr (sec) | Time Constant Separation Multiplier | Minimum Fuel Gas Disturbance Timescale T63 (sec) T63 (min) |           |
|                                                                                                                                                    | T90 <sub>Published</sub>                                | T63 <sub>Estimated</sub>                            |                                                     |             |                                          |                                     | T63 (sec)                                                  | T63 (min) |
| ZrO2                                                                                                                                               | 15                                                      | 11                                                  | 15                                                  | 0.73        | 26                                       | 5                                   | ≥ 130                                                      | ≥ 2.17    |
| COMB                                                                                                                                               | 25                                                      | 15                                                  | 15                                                  | 1.00        | 30                                       | 5                                   | ≥ 150                                                      | ≥ 2.50    |
| CLOSE-COUPLED EXTRACTIVE ANALYZER WITH FOULED SYSTEM (e.g., add 15 sec to T90)<br>(e.g., fouled sample tubing, sample filters, or flame arrestors) |                                                         |                                                     |                                                     |             |                                          |                                     |                                                            |           |
| Sensor Type                                                                                                                                        | Ta = Published/Estimated Analyzer System Response (sec) | Tr = Sample Radiant Section Time Constant T63 (sec) |                                                     | Ratio Ta/Tr | Overall System Response Time Ta+Tr (sec) | Time Constant Separation Multiplier | Minimum Fuel Gas Disturbance Timescale T63 (sec) T63 (min) |           |
|                                                                                                                                                    | T90 <sub>Published</sub>                                | T63 <sub>Estimated</sub>                            |                                                     |             |                                          |                                     | T63 (sec)                                                  | T63 (min) |
| ZrO2                                                                                                                                               | 30                                                      | 18                                                  | 15                                                  | 1.20        | 33                                       | 5                                   | ≥ 165                                                      | ≥ 2.75    |
| COMB                                                                                                                                               | 40                                                      | 22                                                  | 15                                                  | 1.47        | 37                                       | 5                                   | ≥ 185                                                      | ≥ 3.08    |

**Table 1 – Comparison of Overall System Response Times at Design Absorbed Duty**

NOTE 1 For close-coupled extractive analyzers, the analyzer system response time includes both transport delay and sensor response. The estimated T63 values used in Tables 1 and 2 reflect a representative first-order plus dead-time response, with a transport delay of approximately 8 seconds.

NOTE 2 The tabulated values in Tables 1 and 2 are illustrative and can be evaluated against site-specific fuel gas disturbance characteristics and system response.

**6.3.4** Based on Table 1, the following observations apply for a representative fired heater operating at design absorbed duty, based on the response of the oxygen trim measurement to the fuel gas disturbance:

- A fuel gas disturbance time constant (T63) of ≥ 150 seconds generally allows selection of either a close-coupled extractive or laser-based flue gas analyzer.
- A fuel gas disturbance time constant (T63) between approximately 60 and 150 seconds favors selection of a laser-based flue gas analyzer.

**6.3.5** Historically, changes in refinery fuel gas composition at the burners were relatively slow, with fuel gas disturbance time constants (T63) typically on the order of 120 to 180 seconds. Under these conditions, oxygen trim systems using close-coupled extractive analyzers have generally provided acceptable performance at design absorbed duty. With the introduction of hydrogen pressure swing adsorption and flare gas recovery systems, faster fluctuations and step changes in fuel gas composition are increasingly observed. Accordingly, the fuel gas disturbance time constant (T63) should be determined for the specific application prior to selecting flue gas analyzer technology.

**6.3.5.1** At design absorbed duty, if the fuel gas disturbance time constant (T63) is less than 60 seconds, the oxygen trim controller may be challenged to maintain the fired heater within operational limits, even with laser-based technology.

NOTE In such cases, maintaining the fired heater within operational limits may involve temporary operational measures (e.g., reduction in firing rate and/or transfer to manual mode) to allow the disturbance to pass while maintaining sufficient excess air and avoiding sub-stoichiometric combustion. The magnitude of any firing reduction is typically determined by the owner/operator.

| HEATER OPERATING AT TURNDOWN ABSORBED DUTY (ASSUME 3:1 PROCESS TURNDOWN RATIO)                                                                     |                                                         |                                    |                                                     |             |                                          |                                     |                                                            |           |
|----------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|------------------------------------|-----------------------------------------------------|-------------|------------------------------------------|-------------------------------------|------------------------------------------------------------|-----------|
| LASER-BASED ANALYZER (NO SAMPLE SYSTEM)                                                                                                            |                                                         |                                    |                                                     |             |                                          |                                     |                                                            |           |
| Sensor Type                                                                                                                                        | Published Analyzer Response (sec)                       | Ta = Typical Rolling Average (sec) | Sample Radiant Section Time Constant T63 (sec)      | Ratio Ta/Tr | Overall System Response Time Ta+Tr (sec) | Time Constant Separation Multiplier | Minimum Fuel Gas Disturbance Timescale T63 (sec) T63 (min) |           |
| TDL                                                                                                                                                | 2 to 5                                                  | 5                                  | 45                                                  | 0.11        | 50                                       | 3                                   | ≥ 150                                                      | ≥ 2.50    |
| CLOSE-COUPLED EXTRACTIVE ANALYZER WITH CLEAN SYSTEM<br>(e.g., clean sample tubing, sample filters, and flame arrestors)                            |                                                         |                                    |                                                     |             |                                          |                                     |                                                            |           |
| Sensor Type                                                                                                                                        | Ta = Published/Estimated Analyzer System Response (sec) |                                    | Tr = Sample Radiant Section Time Constant T63 (sec) | Ratio Ta/Tr | Overall System Response Time Ta+Tr (sec) | Time Constant Separation Multiplier | Minimum Fuel Gas Disturbance Timescale T63 (sec) T63 (min) |           |
|                                                                                                                                                    | T90 <sub>Published</sub>                                | T63 <sub>Estimated</sub>           |                                                     |             |                                          |                                     | T63 (sec)                                                  | T63 (min) |
| ZrO2                                                                                                                                               | 15                                                      | 11                                 | 45                                                  | 0.24        | 56                                       | 3                                   | ≥ 168                                                      | ≥ 2.80    |
| COMB                                                                                                                                               | 25                                                      | 15                                 | 45                                                  | 0.33        | 60                                       | 3                                   | ≥ 180                                                      | ≥ 3.00    |
| CLOSE-COUPLED EXTRACTIVE ANALYZER WITH FOULED SYSTEM (e.g., add 15 sec to T90)<br>(e.g., fouled sample tubing, sample filters, or flame arrestors) |                                                         |                                    |                                                     |             |                                          |                                     |                                                            |           |
| Sensor Type                                                                                                                                        | Ta = Published/Estimated Analyzer System Response (sec) |                                    | Tr = Sample Radiant Section Time Constant T63 (sec) | Ratio Ta/Tr | Overall System Response Time Ta+Tr (sec) | Time Constant Separation Multiplier | Minimum Fuel Gas Disturbance Timescale T63 (sec) T63 (min) |           |
|                                                                                                                                                    | T90 <sub>Published</sub>                                | T63 <sub>Estimated</sub>           |                                                     |             |                                          |                                     | T63 (sec)                                                  | T63 (min) |
| ZrO2                                                                                                                                               | 30                                                      | 26                                 | 45                                                  | 0.58        | 71                                       | 4                                   | ≥ 284                                                      | ≥ 4.73    |
| COMB                                                                                                                                               | 40                                                      | 30                                 | 45                                                  | 0.67        | 75                                       | 4                                   | ≥ 300                                                      | ≥ 5.00    |

**Table 2 – Comparison of Overall System Response Times at Turndown Absorbed Duty**

**6.3.6** Based on Table 2, the following approximate observations apply for a representative fired heater operating at turndown absorbed duty, based on the response of the oxygen trim measurement to the fuel gas disturbance:

- A fuel gas disturbance time constant (T63) of ≥180 seconds generally allows selection of either a close-coupled extractive or laser-based flue gas analyzer.
- A fuel gas disturbance time constant (T63) between approximately 150 and 180 seconds favors selection of a laser-based flue gas analyzer.

**6.3.6.1** At turndown absorbed duty, if the fuel gas disturbance time constant (T63) is less than 150 seconds, the oxygen trim controller may be challenged to maintain the fired heater within operational limits, even with laser-based technology.

**NOTE** In such cases, maintaining the fired heater within operational limits may involve temporary operational measures (e.g., reduction in firing rate and/or transfer to manual mode) to allow the disturbance to pass while maintaining sufficient excess air and avoiding sub-stoichiometric combustion. The magnitude of any firing reduction is typically determined by the owner/operator.

## 7 Installation Requirements

### 7.1 Ambient Conditions at Nozzle Location

The analyzer nozzle location shall be optimized to minimize the effect of harsh ambient conditions (temperature, wind direction, sunrise / sunset, etc.) along with radiant heat from the process equipment. Additional radiant heat mitigation may be required. Consult with the analyzer manufacturer for minimum and maximum allowable temperatures.

### 7.2 Path-averaged measurement (Laser-Based) – O<sub>2</sub> or CO

Laser based measurements operate in the near-IR (TDL) or mid-IR (QCL) region of the electromagnetic spectrum.

#### 7.2.1 Mounting Requirements

**7.2.1.1** Per API 560, each pair of connections for an in-situ pathlength averaged analyzer shall be opposed, aligned, and concentric. Consult with the analyzer vendor for specific requirements (e.g., mounting pads, gussets, etc.).

NOTE Laser misalignment can lead to signal degradation and ultimately analyzer malfunction.

**7.2.1.2** To reduce the potential for fired heater flexure to misalign the laser across the open path, the analyzer shall have an alignment adjustment mechanism that may be used with the fired heater in operation. This adjustment can be performed manually or automatically.

#### 7.2.2 Nozzle Purge Requirements

**7.2.2.1** The nozzle shall be purged with nitrogen or instrument grade air. Analyzer vendor shall specify the purge utility gas and volumetric flow rate to be used for window / nozzle and optics purging.

**7.2.2.2** Nitrogen is preferred as the purge gas. If instrument air is used in lieu of nitrogen, data from the manufacturer shall be obtained quantifying the impact on the oxygen measurement.

#### 7.2.3 Temperature Compensation

The measurement shall be temperature compensated. A temperature measurement that is representative of flue gas temperature at the analyzer's optical measurement path shall be connected to the analyzer. Refer to API 556-1 for additional information.

NOTE When the reported flue gas temperature measurement is lower or higher than actual, both the laser-based oxygen measurement and the laser-based carbon monoxide measurement are impacted. The offset in oxygen and carbon monoxide indications is proportional to the offset in temperature indication. Approximate offsets are shown in Table 3:

|                              | Actual     | Reported   | Delta     |
|------------------------------|------------|------------|-----------|
| Flue Gas Temperature, °C (F) | 871 (1600) | 816 (1500) | -55 (100) |
| %O <sub>2</sub>              | 3          | 2.55       | -0.45     |
| CO, ppm, volume, wet basis   | 1000       | 850        | -150      |

|                              | Actual     | Reported   | Delta     |
|------------------------------|------------|------------|-----------|
| Flue Gas Temperature, °C (F) | 871 (1600) | 927 (1700) | +56 (100) |
| %O <sub>2</sub>              | 3          | 3.45       | +0.45     |
| CO, ppm, volume, wet basis   | 1000       | 1150       | +150      |

**Table 3 – Temperature Based Offsets**

### **7.3 Point Based Measurement**

#### **7.3.1 Zirconium Oxide – Oxygen**

##### **7.3.1.1 Reference Gas**

**7.3.1.1.1** The reference gas shall be ambient air or instrument air.

**7.3.1.1.2** When instrument air is used as a reference gas for critical control or safety applications, nitrogen shall not be used to back up the instrument air supply.

NOTE In the event that nitrogen is used as the backup reference gas, the analyzer will yield a false high reading.

##### **7.3.1.2 Power to Heated Sensors**

The  $ZrO_2$  sensor shall be electrically heated independent of the flue gas to facilitate accurate reporting during start-up and normal operation.

NOTE 1 An unheated  $ZrO_2$  sensor technology will not allow the sensor to be at proper operating temperature (e.g., above 500-550°C / 930-1020°F) until well after start-up rendering the analyzer's signal unreliable during this critical time. In contrast, an independent heat source allows sensor operation without depending on the flue gas as a heating mechanism.

NOTE 2 While some  $ZrO_2$  sensors may warm-up and stabilize to provide results to published accuracy within 1 hour, others may require up to 6 hours. Monitor the analyzer status to indicate the analyzer is available for normal operation. Refer to the vendor's operation manual for warm-up and stabilization times.

##### **7.3.1.3 Integral Flame Arrestors**

The close-coupled extractive analyzer shall have integral flame arrestors to prevent the propagation of flame to the firebox. See B.2 for supplemental information.

NOTE 1 The  $ZrO_2$  sensor is heated above the auto-ignition temperature of the flue gas.

NOTE 2 With a low oxygen and high combustibles override to the fuel gas controller, fuel gas flow is reduced, limiting exposure of the flame arrestor to a fuel-rich environment and subsequently reducing the potential for flame arrestor failure due to burn-through.

#### **7.3.2 RTD/Catalytic Bead – Combustibles and Methane**

**7.3.2.1** RTD and catalytic bead technologies require the presence of oxygen in the flue gas for combustibles detection. In the absence of oxygen in the flue gas, the analyzer shall either fail-safe or be provided with an alternative source of air to support the combustibles measurement.

NOTE 1 Some sensors may report lower than actual combustible values at low oxygen concentrations. As the measured oxygen concentration approaches 0%, some analyzers will automatically (via software) drive the combustibles measurement to full scale. Other analyzers supply the combustibles sensor with independently sourced "auxiliary, supplemental, or dilution" air to permit combustibles measurement through the low oxygen condition.

NOTE 2 While some combustibles or methane sensors may warm up and stabilize to provide results to published accuracy within 1 hour, others may require up to 6 hours. Monitor the analyzer status to indicate the analyzer is available for normal operation. Refer to the vendor's operation manual for warm-up and stabilization times.

**7.3.2.2** When methane measurement is specified, a separate detector shall be supplied.

### **7.3.3 Laser-based probe – Oxygen, Carbon Monoxide, Methane**

Nozzle purge requirements and temperature compensation apply to the probe-based laser.

**NOTE** The methane measurement may be used to detect unburned fuel gas in the fired heater as part of the post-purge, pre-ignition permissive. With a lower limit of detection, methane may also be used to detect partial loss of flame introducing a hazard.

## **8 Regulations**

The purchaser and the vendor shall mutually determine the measurements required to comply with all local and national regulations applicable to the equipment.

## **9 Proposals and Deliverables**

The purchaser shall define the required proposals, deliverables, and areas of responsibility in the procurement documentation. The procurement documentation shall identify the applicable requirements, responsibilities, and any special requirements or exceptions.

### **9.1 Purchaser's Responsibilities**

**9.1.1** The purchaser's inquiry shall include datasheets (including API 556 analyzer datasheet in Annex A) or equivalent, checklists, and any special requirements or exceptions to this standard.

**9.1.2** The purchaser should complete, as a minimum, those items on the datasheet that are designated by an asterisk (\*).

**9.1.3** The fired heater's API 560 datasheet lists combustion design conditions for normal mode of operation, at start-of-run, end-of-run, and process design cases. In addition, consideration should be given to providing combustion design conditions for one or more of the following cases as part of the analyzer datasheet:

- 1) Startup mode of operation, including:
  - a) burner ignition state of operation;
  - b) ramp-up state of operation.
- 2) Normal mode of operation / turndown state of operation.
- 3) Maintenance mode of operation / coke removal.
- 4) Potential upset conditions.

**9.1.4** The purchaser's inquiry shall state clearly the supplier's scope of supply.

**9.1.5** Performance and guarantee requirements shall be communicated through the equipment datasheets and documentation requirements as defined in the inquiry documents. Specific guarantee requirements for all guaranteed criteria shall be clearly noted in the purchase order.

### **9.2 Supplier's Responsibilities**

**9.2.1** The supplier's proposal shall include:

- 1) Completed datasheets for each analyzer and the associated equipment (see examples in Annex A).
- 2) Description of the full scope of supply and work.
- 3) An outline drawing showing the dimensions of the analyzer and any associated equipment as may be applicable.
- 4) Wiring diagrams. The wiring diagram shall include the signal types (4-20 mA current source, Ethernet data stream, fiber optic, etc.) and shall clearly indicate the terminations required.
- 5) Detailed description of any exceptions to the specified requirements.
- 6) A time schedule for submission of all required drawings, data, and documents.

- 7) A program for scheduling the work after receipt of an order. The program schedule should include a specified period of time for the purchaser to review and return drawings, procurement of materials, manufacture, and the required date of supply.
- 8) A list of utilities with quantities required.
- 9) Equipment warranties.

### **9.2.2 Documents and Drawings for Purchaser's Review**

The supplier shall submit the following documents and drawings for review and approval prior to fabrication:

- 1) Documentation list.
- 2) Confirmation of performance requirements listed on application datasheet.
- 3) Analyzer weights and dimensions.
- 4) Installation manual and details (e.g., mounting pads and bracing, where applicable).

NOTE For laser-based analyzers, proper mounting and bracing are critical to maintaining acceptable nozzle alignment and minimizing the effects of fired heater flexure across the operating temperature range.

- 5) Analyzer power and signal wiring details.
- 6) Auxiliary equipment details (e.g., calibration and purge panels, where applicable).
- 7) A list of utilities required with expected consumption and nominal pressure rating. This may include but is not limited to calibration/validation gas, instrument air, nitrogen, steam, water, electric power (voltage, current, phase requirements).
- 8) Operating and maintenance manual.
- 9) Ongoing inspection, testing and maintenance instructions to meet availability requirements listed on application datasheet.
- 10) Spare parts list.
- 11) Inspection and test plan (ITP) covering all phases of supply.

### **9.2.3 Final Records**

Within a specified time after completion of shop fabrication or shipment, the supplier shall furnish the purchaser with the following documents:

- 1) Completed datasheets.
- 2) General arrangement drawings for each analyzer and all equipment in the scope of work, representing the as-manufactured equipment.
- 3) Detailed wiring and interconnection drawings.
- 4) Installation, operation, and maintenance instructions for the analyzer and auxiliary equipment.
- 5) Bill of materials.
- 6) All other test documents, including test reports and nondestructive examination reports.
- 7) Factory acceptance test results, if applicable.
- 8) Equipment shop-test results.
- 9) Field commissioning reports.

## **10 Inspection, Testing, and Maintenance**

### **10.1 General**

**10.1.1** Performance tests shall be performed when specified by the purchaser.

**10.1.2** The test protocol shall be mutually agreed to by supplier and purchaser.

**10.1.3** The purchaser reserves the right to inspect, after prior notice, all analyzer components and their assembled units at any time during the material procurement, fabrication, and shop assembly to ensure

materials and workmanship are in accordance with applicable standards, specifications, codes, and drawings.

**10.1.4** The vendor shall examine all individual analyzer components and their shop-assembled units to ensure that materials and workmanship are in accordance with applicable standards, specifications, codes, and drawings.

**10.1.5** If specified by the purchaser, pre-inspection meetings between the purchaser and the equipment manufacturer shall be held before the start of fabrication.

## **10.2 Positive Materials Identification (PMI)**

**10.2.1** The purchaser shall specify the components that are subject to PMI (e.g., sample probes).

**10.2.2** PMI program methods, degree of examination, PMI testing instruments, and tester qualifications shall be agreed upon between the purchaser and the vendor prior to manufacturing.

## **10.3 Ongoing Inspection & Preventive Maintenance**

This section provides guidance on using analyzer diagnostic capabilities to assess analyzer condition and inform inspection, testing, validation, calibration, and maintenance practices.

### **10.3.1 Diagnostic Capabilities**

**10.3.1.1** Calibration and maintenance practices for flue gas analyzers should account for the diagnostic capabilities of the applied measurement technology (e.g., close-coupled extractive and laser-based analyzers). Using available diagnostic information to assess analyzer condition and inform maintenance decisions supports measurement reliability and stable operation, helps avoid unnecessary maintenance, and enables timely intervention when degradation or abnormal performance is indicated. Condition-informed maintenance is not intended to support “run to failure,” but rather to enable timely and appropriate intervention based on observable analyzer condition.

**10.3.1.2** Close-coupled extractive analyzers can provide diagnostics such as cell millivolt (mV) output, cell resistance, temperature verification, and sample flow indication, along with system-level indicators such as service alarms and data validity status. Trending these parameters may provide an early indication of sensor aging, contamination, or sample system issues (e.g., plugging or leakage) that may affect measurement accuracy or validity.

**10.3.1.3** Laser-based analyzers can provide diagnostics including signal strength, optical alignment, nozzle purge flow, path integrity, and spectral fit quality. These indicators provide operators with greater confidence in the validity of analyzer measurements and can help identify fouling, beam obstruction, process-related interferences, or laser line position issues.

**10.3.1.4** Modern analyzer systems provide embedded diagnostics that can be used to evaluate measurement validity and analyzer health during operation. Users should understand and use these diagnostics to support condition-informed maintenance practices, rather than relying solely on fixed calibration intervals. Effective use of diagnostic information can help optimize maintenance schedules, improve system reliability, and reduce unnecessary maintenance interventions while maintaining measurement confidence.

### **10.3.2 Diagnostic Interpretation and Condition Assessment**

**10.3.2.1** For both close-coupled extractive and laser-based analyzers, proper interpretation of measurement validity indicators (e.g., service or diagnostic alarms, and maintenance or calibration status indications) is essential to distinguish reliable measurements from those obtained during calibration, warm-up, or diagnostic fault conditions and to determine when intervention is required.

**10.3.2.2** Effective use of flue gas analyzer diagnostics requires appropriate user understanding of measurement principles, diagnostic indicators, and process context. While procedures and guidance can support consistent application, achieving reliable outcomes depends on trained personnel exercising sound technical judgment in interpreting analyzer condition and responding to abnormal indications. This expectation is consistent with established process safety management requirements for training and

competency and reflects the limitations of prescriptive, checklist-based approaches when used in place of such judgment. Accordingly, this standard does not redefine these requirements but provides technical guidance to support their effective implementation.

**10.3.2.3** When properly interpreted and acted upon, analyzer diagnostics support improved measurement reliability by enabling earlier detection and correction of analyzer-related issues, reducing unnecessary process disturbances, and providing meaningful insight into analyzer condition and performance. These capabilities support maintenance decisions based on observed analyzer condition and diagnostic trends rather than reliance solely on fixed maintenance intervals.

**10.3.2.4** Condition-informed maintenance provides an assessment of analyzer system condition and reliability beyond what can be established through calibration alone. Although calibration can establish or restore measurement accuracy, it does not necessarily represent the analyzer's overall system reliability and availability, remaining useful life, operational stability, or the repeatability and condition of individual components.

**10.3.2.5** An analyzer requiring increasingly frequent adjustment to remain within tolerance may continue to satisfy calibration acceptance criteria while exhibiting progressive degradation. Evaluation of analyzer diagnostics, as-found performance, calibration history, and diagnostic trends can provide an early indication of such degradation and support maintenance or component replacement before measurement reliability is adversely affected. Accordingly, this approach is intended to complement—not replace—periodic calibration by providing additional information regarding analyzer health and measurement integrity throughout the analyzer lifecycle.

### **10.3.3 Validation and Calibration**

**10.3.3.1** Validation intervals should be established by the owner based on analyzer technology, diagnostic capability, fuel composition, service severity, manufacturer recommendations, and documented operating experience. The analyzer should be validated prior to initial startup, when diagnostic trends indicate abnormal performance, and at the manufacturer-recommended frequency appropriate for the application. Validation intervals may be adjusted based on changes in contaminants known to accelerate degradation, documented operating experience, and the effective use of diagnostic information.

**10.3.3.2** Laser-based analyzers are generally designed for routine validation rather than calibration. When validation results meet the specified acceptance criteria and performance trends remain normal, calibration is not required. These analyzers are more commonly affected by degradation of the optical measurement path due to fouling, contamination, or misalignment. If validation results fall outside the manufacturer's specified acceptance criteria or data analysis indicates abnormal behavior, a root cause analysis should be conducted to identify the underlying cause. Any subsequent calibration is typically performed by the manufacturer's factory-trained personnel.

**10.3.3.3** Zirconium oxide and catalytic combustibles analyzers are designed for field calibration; however, calibration may not be necessary if the analyzer responds to validation gas within the specified tolerance and the validation procedure and calibration practices are consistent with the manufacturer's recommendations. These analyzers incorporate sensing elements that can be affected by exposure to sulfur-bearing compounds, particulate fouling, and other contaminants. These exposures may contaminate sensing surfaces, obstruct gas access, or deactivate catalytic sites, resulting in reduced sensitivity, slower response, or loss of measurement capability. The effects and rate of change depend on the sensing technology, fuel gas composition, and operating conditions. If validation results fall outside the manufacturer's specified acceptance criteria, a root cause analysis should be conducted to identify the underlying cause, and corrective action should be determined accordingly.

**10.3.3.4** Acceptable validation results demonstrate performance within the specified criteria at the time of testing but do not necessarily indicate the condition or remaining useful life of consumable sensing elements or other analyzer components. Similarly, calibration can establish or restore measurement accuracy at the time it is performed but does not, by itself, establish component condition or its remaining useful life.

#### **10.3.4 Performance-Based Guidance**

This standard provides performance-based guidance and does not prescribe calibration intervals, diagnostic thresholds, or maintenance frequencies. Such practices should be established by the owner in accordance with recognized and generally accepted good engineering practices (RAGAGEP), manufacturer recommendations, and applicable regulatory requirements. The guidance provided herein supports maintenance implementation and does not establish compliance criteria or assign quantifiable risk reduction.

#### **10.3.5 Operational Benefits**

Good maintenance practices, including effective use of flue gas analyzer diagnostics, support measurement reliability and operational awareness and can help sustain the operating conditions underlying the low-demand mode assumption commonly used in order-of-magnitude risk reduction analysis (e.g., Layer of Protection Analysis). These practices can reduce unnecessary demands on protective functions; however, their effectiveness depends on robust constraint control, appropriate selection of control override setpoints, effective operator response to alarms, and alarm management practices that maintain adequate margins between control setpoints and alarm or trip thresholds. These margins are frequently narrowed in practice when equipment is operated near or beyond design limits, with real-world consequences. Outcomes are also frequently influenced by operating conditions such as step changes in refinery fuel gas composition. Consistent application of flue gas analyzer diagnostic capability and disciplined maintenance practices is essential to achieving reliable and stable performance.

## **ANNEX A** **(informative)**

Flue Gas Analyzer Equipment Datasheets – included for reference only

For API Committee Review Only

## **ANNEX B** **(informative)**

### **Flue Gas Analyzer Supplemental Information**

#### **B.1 Evaluating the T90 Analyzer System Response Time**

Response time procedure with point-based ZrO<sub>2</sub> analyzer installed on fired heater:

- Note the flue gas analyzer indication before starting test.
- Open the calibration gas valve to apply instrument air or a known calibration gas.
- Close the calibration gas valve and sample the flue gas. Note the time to reach 90% of the difference between starting concentration and previously noted flue gas concentration.
  - Example: If flue gas is 3% oxygen and the starting concentration is 20.9% oxygen, an indication of 4.79% should be achieved within 15 seconds to meet the specification (the delta is 17.9%, 90% of which is 16.11%...20.9-16.11 = 4.79%).

#### **B.2 Flame Arrestors**

Flame arrestors perform the mechanical function of reducing the propagation of a deflagration. Their design is prone to two potential sources of failure: plugging and corrosion. A plugged or partially restricted flame arrestor would be a failure in the safe direction with regards to the flame arrestor functionality; however, this would negatively impact the analyzer function creating an unsafe condition as the analysis results would be incorrect or delayed. A flame arrestor with corroded or missing internals may no longer function as designed resulting in a dangerous failure mode. Precautions for corrosive environments may require the use of alloys, including Inconel or Hastelloy C, for flame arrestor construction. The most problematic environment is during an equipment shutdown which could accumulate liquid that can cause corrosion of the flame arrestors and all other parts.

The integrity of the flame arrestors should be verified at a prescribed inspection interval to monitor and detect plugging and corrosion. This verification could be performed through a visual inspection or functional test, including verification of inline flow sensor or DP flow measurements. The inspection and testing intervals vary based on the consistency and corrosivity of the process and compatibility of the materials of the device.

#### **B.3 ZrO<sub>2</sub> Sensors Ratio of Consumption**

ZrO<sub>2</sub> sensors are “net oxygen” analyzers which are heated (i.e., typically 550-800°C / 1020-1470°F), utilize a platinum electrode with catalytic properties, and will burn any combustible compounds with oxidation potential such as carbon monoxide, hydrogen, and high concentrations of sulfur dioxide, etc. The analyzer will indicate the resulting oxygen after the combustion is complete which is typically a slightly lower value than the gross oxygen concentration.

During combustibles breakthrough, hydrogen and carbon monoxide are typically the largest combustible components. The ratio of consumption for hydrogen or carbon monoxide to oxygen at a heated ZrO<sub>2</sub> sensor is approximately 2:1. As an example, a sample with 2000 ppm (0.2 %) hydrogen and carbon monoxide has the potential to consume 0.1 % oxygen at the sensor. Likewise, a sample with 10,000 ppm (1.0 %) hydrogen and carbon monoxide has the potential to consume 0.5 % oxygen at the sensor. Therefore, at low oxygen levels, it is possible for high concentrations of hydrogen and carbon monoxide to mask (malfunction low) the true oxygen concentration at the sensor.

Upon complete loss of flame, methane may be the largest component. The ratio of consumption of methane to oxygen at a heated ZrO<sub>2</sub> sensor is approximately 1:2. As an example, a sample with 1 % methane has the potential to consume 2 % oxygen at the sensor. Likewise, a sample with 5 % methane has the potential to

consume 10 % oxygen at the sensor. Therefore, in a fuel rich environment, it is possible for a high concentration of methane to mask (malfunction low) the true oxygen concentration at the sensor.

## B.4 ZrO<sub>2</sub> Sensor Signal Response

A ZrO<sub>2</sub> oxygen sensor uses the difference in partial pressure between a sample and reference gas, typically air. Oxygen concentration and the sensor's signal (typically in mV) output are inversely proportional and dependent on the oxygen sensor's temperature. For example, when the sample gas is ambient air (20.9% oxygen), the output from the sensor will be 0 mV. The relationship between oxygen concentration and sensor mV output is logarithmic as the oxygen concentration decreases, as governed by the Nernst Equation. As the oxygen concentration in the sample gas decreases, the mV output signal from the sensor increases.

Table B.1 shows the ZrO<sub>2</sub> cell mV output correlated to Oxygen concentration. These numbers assume the ZrO<sub>2</sub> cell is operated at 680°C.

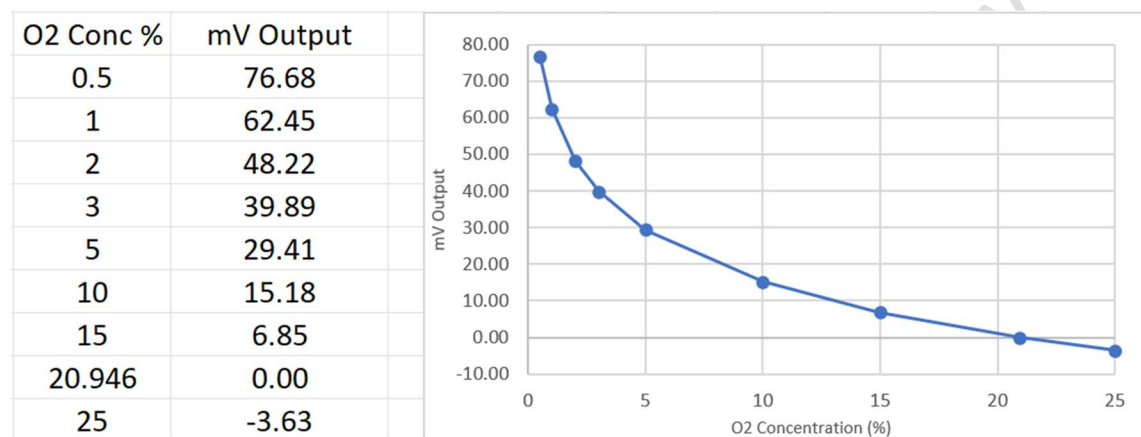


Table B.1 – Chart of O<sub>2</sub> versus Cell mV output

## B.5 Point-based Sample Location Quantity in Large Fireboxes

For large combustion zones, one analyzer for every 10 m (30 ft) of firebox length is recommended due to non-uniformities in the firebox flue gas circulation and to facilitate balancing the burners. Oxygen measurements should be taken as near as possible to the point where combustion is completed, normally at the exit of the radiant section and before the transition to the convection section to minimize the potential effects of tramp air ingress. Stack measurements for oxygen concentrations are generally less desirable where air ingress may affect the measurement. If a stack sample is utilized, a portable oxygen analyzer should be used to prove fired heater integrity (no air leaks) by directly correlating the stack measurement with the oxygen concentration leaving the radiant section. Stack measurement for control is an option only if the fired heater is properly sealed.

## B.6 Close-Coupled Extractive Analyzer - Sample Probe Length

The location of the sampling point within the flue gas stream is important in obtaining a representative sample. For analyzers located at the bridgewall, sample probes may penetrate into the furnace 600 mm (24 in.) or more from the inside wall. Customized probe lengths are available to ensure the sample taken is representative of the flue gas flowing out of the radiant section. With longer probes, the vendor may offer additional probe support. Generally, the probe tip should be in the middle third of the duct, stack, or sampling area.

## **B.7 Methane Measurement for Post-Purge, Pre-Ignition Permissive**

Historically, burner management systems have relied on purge duration and flammable gas concentrations less than 25% of the Lower Explosive Limit (LEL) to establish readiness for ignition following a purge. API 556-5 recognizes that delayed ignition of accumulated fuel during the Trial-for-Ignition (TFI) period is the governing hazard during burner light-off. As a core principle, API 556-5 recommends limiting burner ignition intensity such that the resulting delayed ignition pressure rise does not exceed 50 mbar (0.73 psi). This consequence-based approach recognizes that, particularly for natural draft heaters, acceptable residual fuel concentrations at the end of the purge cycle may be substantially lower than the historical 25% LEL criterion.

Following completion of the required purge sequence and immediately prior to ignition, methane measurement may be used as an additional permissive to verify that flammable gas concentrations have been reduced to an acceptable level before introducing an ignition source. The methane measurement is intended to supplement, and not replace, purge timing, airflow or draft verification, and other burner management safeguards.

Since methane analyzer technologies vary, the post-purge, pre-ignition methane permissive should be established based on the demonstrated capability of the complete analyzer system, including sensor technology, sampling system, response time, and measurement uncertainty. No single methane threshold is appropriate for all analyzer technologies.

The selected methane permissive should not be established at the practical lower detection limit (LDL) of the analyzer. Rather, sufficient measurement margin should be maintained to ensure that the permissive remains reliable over the expected range of operating and environmental conditions.

- As an example, catalytic bead technology with a practical LDL of approximately 0.4 vol% CH<sub>4</sub> and a measurement range of 0 – 5 vol% CH<sub>4</sub> may support a post-purge, pre-ignition permissive with approximately 10:1 turndown from full scale (e.g., < 0.5 vol% CH<sub>4</sub>), while maintaining measurement margin above the LDL.
- As an example, laser-based technology with a practical LDL of approximately 0.01 vol% CH<sub>4</sub> (i.e., assuming a 1-meter pathlength) and a measurement range of 0 – 5 vol% CH<sub>4</sub> may support a post-purge, pre-ignition permissive with approximately 50:1 turndown from full scale (e.g., < 0.1 vol% CH<sub>4</sub>), while maintaining measurement margin above the LDL.

End users should verify that the selected permissive is supported by the demonstrated capability of the applied methane analyzer system and associated measurement uncertainty.

## **Bibliography**

API Recommended Practice 555, *Process Analyzers*

API Standard 556-1 *Instrumentation, Control, and Protective Functions for Gas-Fired Heaters - Part 1: Instrumentation*

API Standard 556-2 *Instrumentation, Control, and Protective Functions for Gas-Fired Heaters - Part 2: Control*

API Standard 556-3 *Instrumentation, Control, and Protective Functions for Gas-Fired Heaters - Part 3: Protective Functions*

API Standard 556-5 *Instrumentation, Control, and Protective Functions for Gas-Fired Heaters - Part 5: Main Burner Ignition Criteria*