INSTRUCTION MANUAL

TGA200 Trace Gas Analyzer Overview

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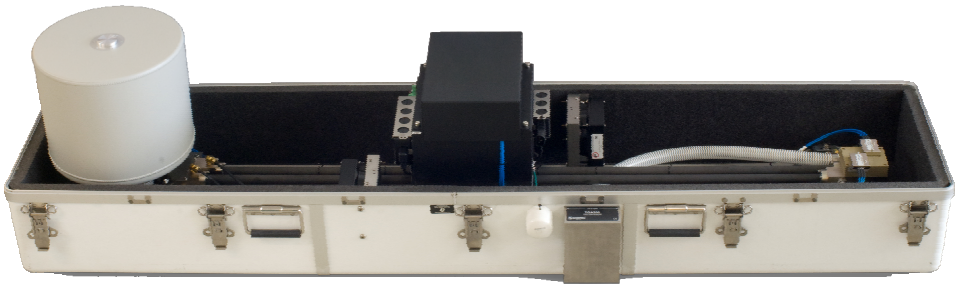

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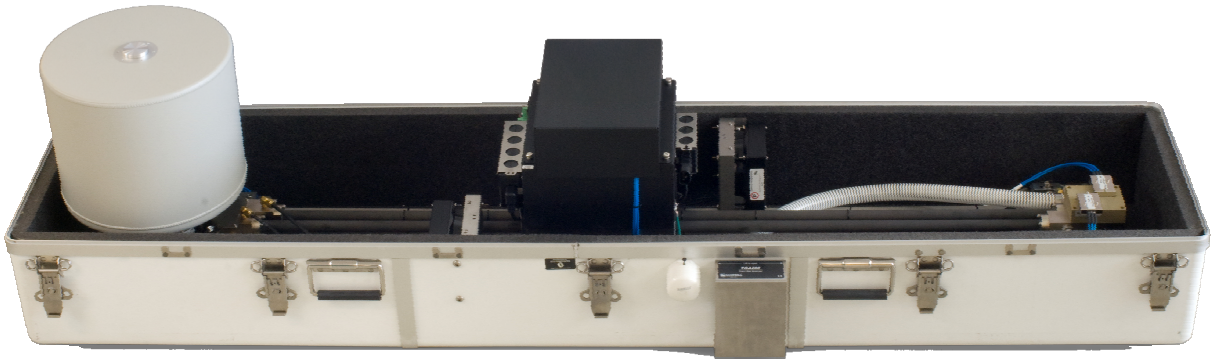

The TGA200 Trace Gas Analyzer measures trace gas concentration in an air sample using tunable diode laser absorption spectroscopy (TDLAS). This technique provides high sensitivity, speed, and selectivity. The TGA200 is a rugged, portable instrument designed for use in the field. It can measure one of a large number of gases by choosing appropriate lasers and detectors.

1. System Components

Figure 1-1 illustrates the main system components as well as additional equipment needed to operate the TGA200. These system components include:

- TGA200 Analyzer
- Sample intake (15838 shown): Filters the air sample and controls its flow rate.
- Sample pump (RB0021-L shown): Pulls the air sample and reference gas through the analyzer at a low pressure.
- Reference gas: Tank of reference gas, with pressure regulator (supplied by user).
- Reference gas connection (15837 shown): Flow meter, needle valve, and tubing to connect the reference gas to the analyzer.
- Datalogger (CR3000 shown)
- Computer (supplied by user): Used to check status and set parameters in the TGA200.

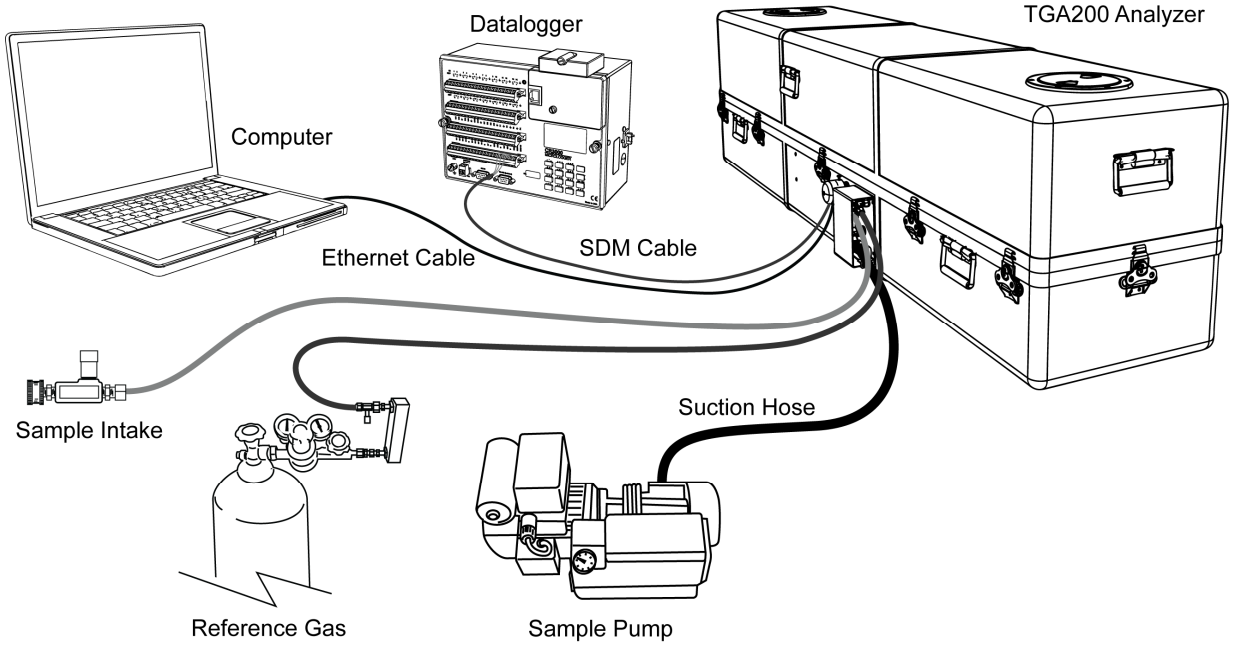

FIGURE 1-1. TGA200 system components

2. Theory of Operation

2.1 Optical System

The TGA200 optical system is shown schematically in Figure 2-1. The optical source is a lead-salt tunable diode laser that operates between 80 and 140 K, depending on the individual laser. The TGA200 LN2 Laser Dewar includes a laser mount that can accommodate one or two lasers. The LN2 Laser Dewar mounts inside the analyzer enclosure. It holds 14.5 liters of liquid nitrogen and must be refilled once per week.

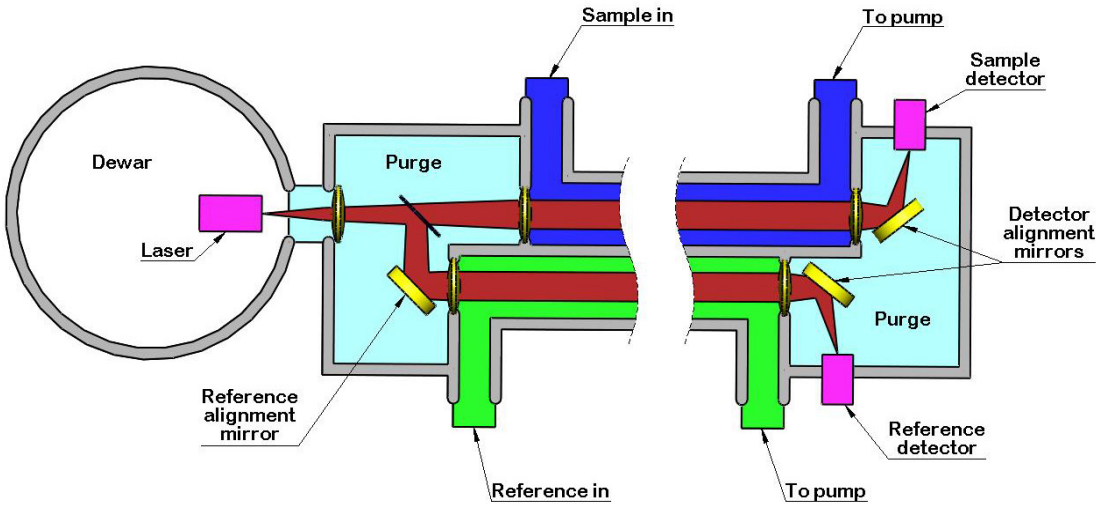

FIGURE 2-1. Schematic diagram of TGA200 optical system

The laser is simultaneously temperature and current controlled to produce a linear wavelength scan centered on a selected absorption line of the trace gas. A beam splitter allows most of the energy from the laser to pass through a 1.5 m sample cell, where it is absorbed proportional to the concentration of the target gas. A lens at the outlet of the sample cell focuses the beam onto the sample detector. The portion of the beam that is reflected by the beamsplitter passes through a reference cell similar to the sample cell and is focused on the reference detector. A prepared reference gas having a known concentration of the target gas flows through the reference cell. The reference signal provides a template for the spectral shape of the absorption line, allowing the concentration to be derived independent of the temperature or pressure of the sample gas or the spectral positions of the scan samples. The reference signal also provides feedback for a digital control algorithm to maintain the center of the spectral scan at the center of the absorption line. The simple optical design avoids the alignment problems associated with multiple-path absorption cells. The number of reflective surfaces is minimized to reduce errors caused by Fabry-Perot interference.

2.2 Laser Scan Sequence

The laser is operated using a scan sequence that includes three phases: the modulation phase, the zero-current phase, and the high-current phase, as illustrated in Figure 2-2. The modulation phase performs the actual spectral scan. During this phase the laser current is increased linearly over a small range (typically ±0.5 to 1 mA). The laser's emission wavenumber depends on its current. Therefore, the laser's emission is scanned over a small range of frequencies (typically ±0.03 to 0.06 cm^{-1}).

During the zero-current phase, the laser current is set to a value below the laser's emission threshold. "Zero" signifies that the laser emits no optical power; it does not mean the current is zero. The zero-current phase is used to measure the detector's dark response, i.e., the response with no laser signal.

The reduced current during the zero-current phase dissipates less heat in the laser, causing it to cool slightly. The laser's emission frequency depends on its temperature as well as its current. Therefore, the temperature perturbation caused by reduced current during the zero-current phase introduces a perturbation in the laser's emission frequency. During the high-current phase, the laser current is increased above its value during the modulation phase to replace the heat "lost" during the zero-current phase. This stabilizes the laser temperature quickly, minimizing the effect of the temperature perturbation. The entire scan sequence is repeated every 2 ms. Each scan is processed to give a concentration measurement every 2 ms (500 Hz sample rate).

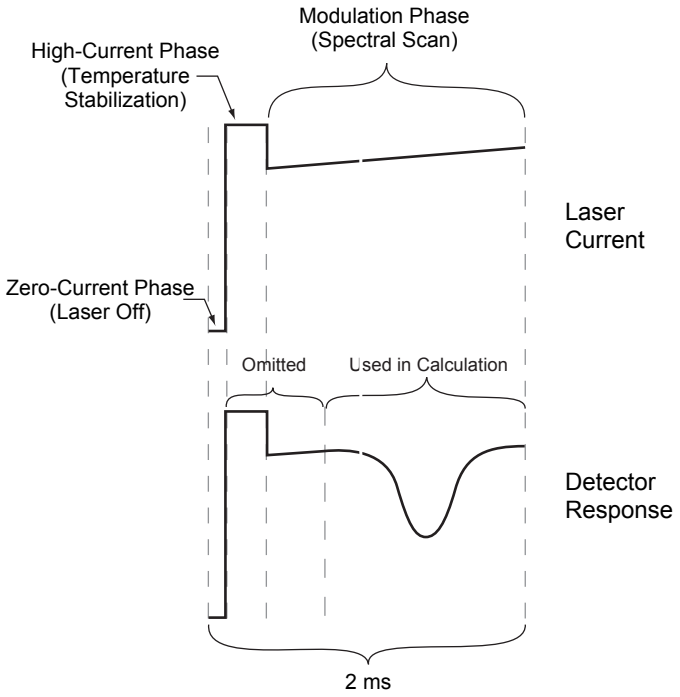

FIGURE 2-2. TGA200 laser scan sequence

2.3 Concentration Calculation

The reference and sample detector signals are digitized, corrected for detector offset and nonlinearity, and converted to absorbance. A linear regression of sample absorbance vs. reference absorbance gives the ratio of sample absorbance to reference absorbance. The assumption that temperature and pressure are the same for the sample and reference gases is fundamental to the design of the TGA200. It allows the concentration of the sample, C_S, to be calculated by

$$C_S = \frac{C_R L_R D}{L_S}$$

Where C_R = concentration of reference gas, ppm

L_R = length of the reference cell, cm

L_S = length of the sample cell, cm

D = ratio of sample to reference absorbance

3. Trace Gas Species Selection

The TGA200 can measure gases with absorption lines in the 3 to 10 micron range by selecting appropriate lasers, detectors, and reference gas. Lead-salt tunable diode lasers have a limited tuning range, typically 1 to 3 cm^{-1} within a continuous tuning mode. In some cases more than one gas can be measured with the same laser, but usually each gas requires its own laser. The laser dewar has two laser positions available (four with an optional second laser mount), allowing selection of up to four different species by rotating the dewar, installing the corresponding cable, and performing a simple optical realignment.

The standard detectors used in the TGA200 are Peltier cooled and operate at wavelengths up to 5 microns. These detectors are used for most gases of interest, including nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2). Some gases, such as ammonia (NH_3), have the strongest absorption lines at longer wavelengths and require the optional long-wavelength, liquid nitrogen-cooled detectors. These detectors operate to wavelengths beyond 10 microns. The detector dewars have a liquid nitrogen capacity of 6.0 liters and must be filled twice per week.

A prepared reference gas having a known concentration of the target gas must flow through the reference cell. The beam splitter directs a small fraction of the laser power through the reference cell to the reference detector. This gives a reference signal proportional to the laser power, with the spectral absorption signature of the reference gas. The reference signal provides a template for the spectral shape of the absorption feature, allowing the concentration to be derived without measuring the temperature or pressure of the sample gas, or the spectral positions of the scan samples.

4. Multiple Ramp Mode

The TGA200 can be configured to measure two or three gases simultaneously by alternating the spectral scan wavelength between nearby absorption lines. This technique requires that the absorption lines be very close together (within about 1 cm^{-1}), so it can be used only in very specific cases. The multiple ramp mode is used to measure isotope ratios in carbon dioxide by tuning each ramp to a different isotopolog.

The multiple ramp mode may also be used to measure some other pairs of gases, such as nitrous oxide and carbon dioxide or nitrous oxide and methane, but the measurement noise will generally be higher than if a single gas is measured. For measurements of a single gas, the laser wavelength is chosen for the strongest absorption lines of that gas. Choosing a laser that can measure two gases simultaneously involves a compromise. Weaker absorption lines must be used in order to find a line for each gas within the laser's narrow tuning range.

5. User Interface

The TGA200 includes TGA Windows software. Illustrated in Figure 5-1, TGA Windows displays data in real time, allows modification of control parameters, and saves data to the hard disk.

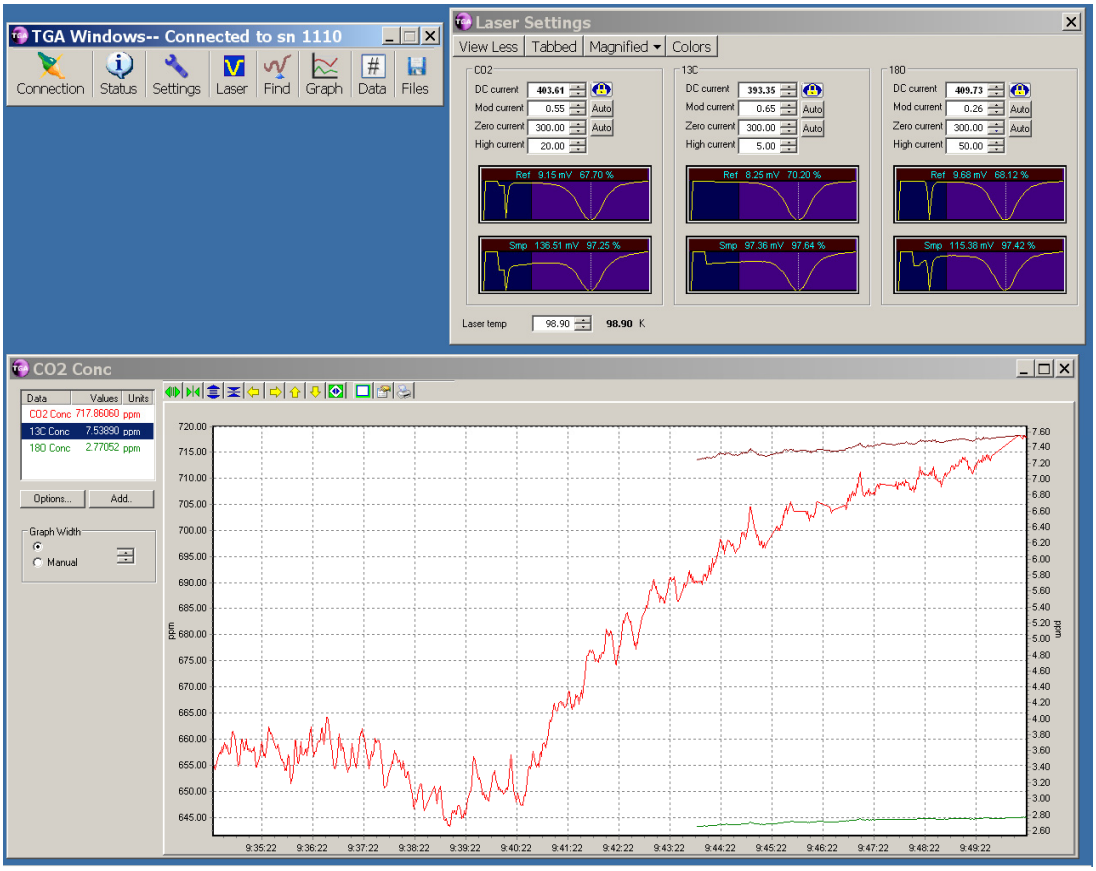

FIGURE 5-1. Real-time graphics screen

6. Specifications

6.1 Measurement Noise

The typical 10 Hz-concentration measurement noise, given in Table 6-1, is calculated as the square root of the Allan variance with 100 ms averaging (i.e., the two-sample standard deviation). This is comparable to the standard deviation of the 10 Hz samples calculated over a relatively short time (10 s). The typical 30-minute average gradient resolution is given as the standard deviation of the difference between two intakes, averaged over 30 minutes, assuming typical valve switching parameters.

TABLE 6-1. Typical Concentration Measurement Noise

Gas		Wave number (cm^{-1})	10 Hz Noise (ppbv)	30-min Gradient Resolution (pptv)
Nitrous Oxide	N_2O	2208.575	1.5	30
Methane	CH_4	3017.711	7	140
Ammonia	NH_3	1065.56	6	200

The TGA200 multiple-scan mode can be used to measure suitable pairs of gases. Typical performance for some examples is given in Table 6-2.

TABLE 6-2. Typical Concentration Measurement Noise for Multiple Scan Lasers

Gas		Wave number (cm^{-1})	10 Hz Noise (ppbv)	30-min Gradient Resolution (pptv)
Nitrous Oxide and Methane	N_2O	1271.077	7	140
	CH_4	1270.785	18	360
Nitrous Oxide and Carbon Dioxide	N_2O	2243.110	1.8	35
	CO_2	2243.585	300	6000

Typical performance for isotope ratio measurements is given in delta notation. For example, the $\delta^{13}C$ for CO_2 is given by

$$\delta^{13}C = \left(\frac{R_S}{R_{VPDB}} - 1 \right) \times 1000$$

where R_s is the ratio of the isotopolog concentrations measured by the TGA200 ($^{13}CO_2/^{12}CO_2$) and R_{VPDB} is the standard isotope ratio ($^{13}C/^{12}C$). $\delta^{13}C$ is reported in parts per thousand (per mil or ‰). The 10 Hz noise is the square root of the Allan variance with no averaging. The calibrated noise assumes a typical sampling scenario: two air sample intakes and two calibration samples measured in a 1-minute cycle. It is given as the standard deviation of the calibrated air sample measurements.

TABLE 6-3. Typical Isotope Ratio Measurement Noise				
Gas	**Isotope Ratio**	**Wavenumber (cm^{-1})**	**10 Hz Noise**	**Calibrated Noise (‰)**
Carbon Dioxide $\delta^{13}C$ only	CO_2	2293.881	0.15 ppm	0.03 ppm
	$\delta^{13}C$	2294.481	0.5 ‰	0.1 ‰
Carbon Dioxide $\delta^{13}C$ and $\delta^{18}O$	CO_2	2310.686	0.5 ppm	0.1 ppm
	$\delta^{13}C$	2310.347	1.5 ‰	0.3 ‰
	$\delta^{18}O$	2310.206	1.5 ‰	0.3 ‰

6.2 TGA200 Frequency Response

There are several issues related to the frequency response of the TGA200, including measurement rate, sample rate, digital filtering, synchronicity, and flow and pressure in the sample cell.

Measurement rate: 500 Hz

Onboard digital filter: user-configurable

Sample cell volume: 420 ml

Frequency response (half-power bandwidth at 10 slpm, 20 mb): 7.5 Hz

The TGA200's frequency response was measured by quickly injecting a small amount of CO_2 into the sample flow, at the TGA200's sample inlet. The data were sampled at 50 Hz, and the onboard digital filter was disabled. An example of the concentration time series is shown in Figure 6-1. The flow was 10 slpm and the pressure was 20 mb, for a calculated residence time of 50 ms. The width of the pulse at half-peak height is approximately 50 ms, as expected.

The measured frequency response (Fourier transform of the measured pulse) is shown in Figure 6-2. The blue curve is the measured frequency response. The purple curve is a model of the frequency response. This model includes two components, shown individually in green and red. The green curve is a sync function, which is the ideal frequency response assuming no mixing of the air sample as it travels to, or through, the sample cell. The blue (measured) curve is below the green (ideal modeled) response, indicating some mixing does occur. The red curve is the frequency response of an ideal mixing volume, with a residence time (exponential time constant) of 14 ms. This residence time is chosen empirically such that the combined effect (purple curve) matches the measured response. These results and data at other flows and pressures confirm that the TGA200's frequency response is well represented by the combination of an ideal sync function and an exponential function with time constant equal to 1/5 of the sample cell residence time.

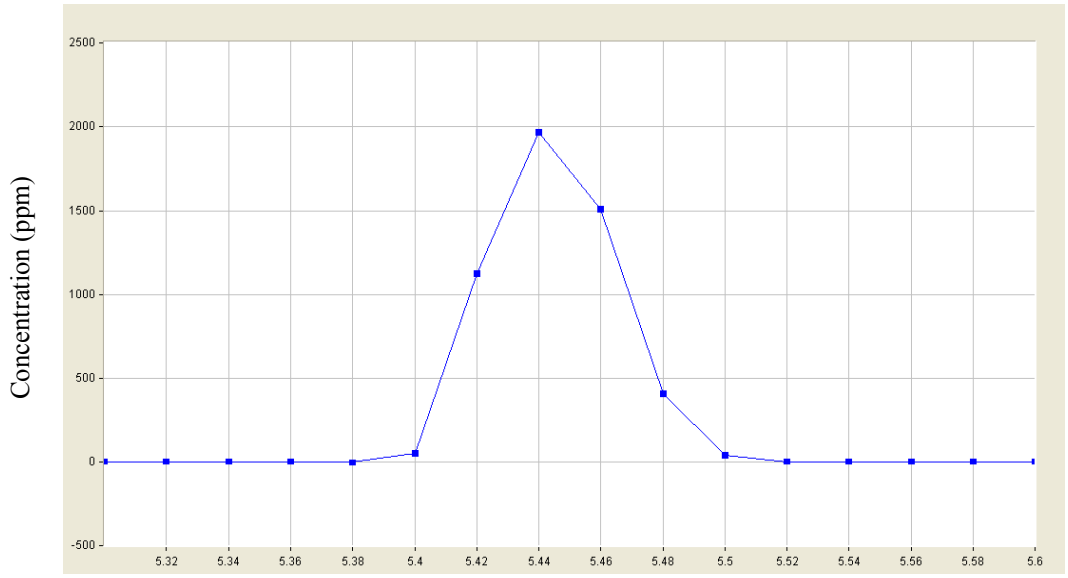

FIGURE 6-1. Concentration time series showing response of TGA200

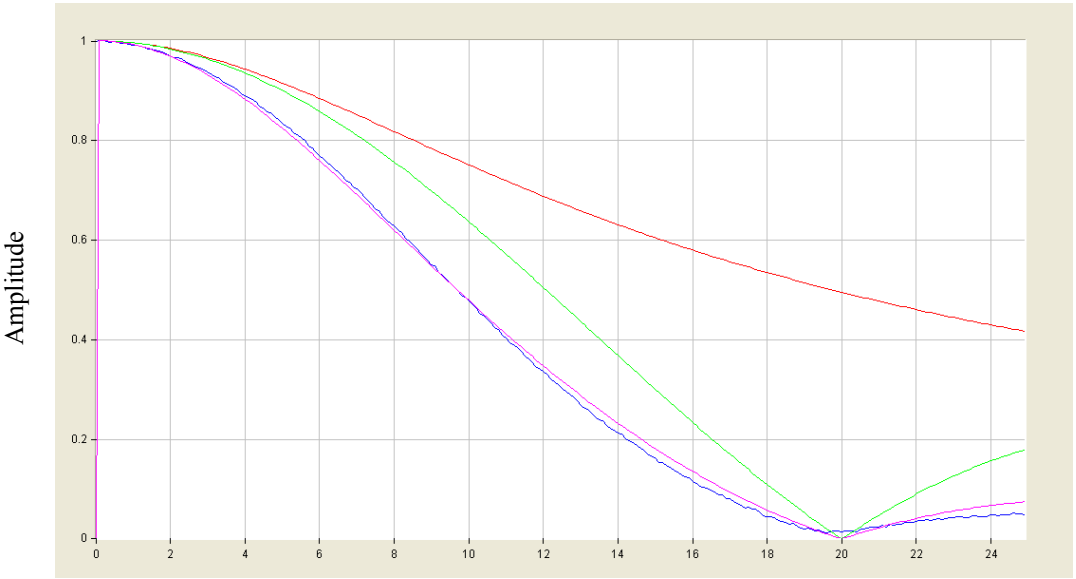

FIGURE 6-2. Frequency response of the TGA200.
The blue line is the measured response, the red line is the model response, the green line is the ideal response, and the red line is the response time of an ideal mixing volume with residence time of 14 ms.

6.3 Physical Specifications

Length: 211 cm (83 in)

Width: 47 cm (18.5 in)

Height: 55 cm (21.5 in)

Weight with peltier-cooled detectors: 78.6 kg (173 lb)

Weight with LN2 detectors: 84.1 kg (185 lb)

Power Requirements

Analyzer: 90-264 Vac, 47-63 Hz, 50 W (max) 30 W (typical)

Heater: 90-264 Vac, 47-63 Hz, 150 W (max) 30 W (typical)

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