produce accurate results, exact conformance with the drawing is not required. Additional components such as instruments, valves, solenoids, pumps and switches may be used to provide additional information and coordinate the functions of the component systems. Other components such as stubbers, which are not needed to maintain accuracy in some systems, may be excluded if their exclusion is based on good engineering judgement.

(b) Major component description. The analytical system, Figure 4 in Appendix B of this subpart, consists of a flame ionization detector (FID) or a heated flame ionization detector (HFID) for the measurement of hydrocarbons, nondispersive infrared analyzers (NDIR) for the measurement of carbon monoxide and carbon dioxide, and a chemiluminescence detector (CLD) (or heated CLD (HCLD)) for the measurement of oxides of nitrogen. The exhaust gas analytical system shall conform to the following requirements:

(1) The CLD (or HCLD) requires that the nitrogen dioxide present in the sample be converted to nitric oxide before analysis. Other types of analyzers may be used if shown to yield equivalent results and if approved in advance by the Administrator.

(2) If CO instruments are used which are essentially free of CO2 and water vapor interference, the use of the conditioning column may be deleted. (See §§91.317 and 91.320.)

(3) Measurements of the various flowmeter parameters are recorded and related to flow through the CVS.

(c) Alternate analytical systems. Analysis systems meeting the specifications and requirements of this subpart for dilute sampling may be used upon approval of the Administrator.

(d) Other analyzers and equipment. Other types of analyzers and equipment may be used if shown to yield equivalent results and if approved in advance by the Administrator.

§ 91.424 Dilute sampling procedure—CVS calibration.

(a) The CVS is calibrated using an accurate flowmeter and restrictor valve. (1) The flowmeter calibration shall be traceable to the National Institute for Standards and Testing (NIST), and will serve as the reference value (NIST “true” value) for the CVS calibration.

(b) Major component description. The analytical system, Figure 4 in Appendix B of this subpart, consists of a flame ionization detector (FID) or a heated flame ionization detector (HFID) for the measurement of hydrocarbons, nondispersive infrared analyzers (NDIR) for the measurement of carbon monoxide and carbon dioxide, and a chemiluminescence detector (CLD) (or heated CLD (HCLD)) for the measurement of oxides of nitrogen. The exhaust gas analytical system shall conform to the following requirements:

(1) The CLD (or HCLD) requires that the nitrogen dioxide present in the sample be converted to nitric oxide before analysis. Other types of analyzers may be used if shown to yield equivalent results and if approved in advance by the Administrator.

(2) If CO instruments are used which are essentially free of CO2 and water vapor interference, the use of the conditioning column may be deleted. (See §§91.317 and 91.320.)

(3) A CO instrument will be considered to be essentially free of CO2 and water vapor interference if its response to a mixture of three percent CO2 in N2, which has been bubbled through water at room temperature, produces an equivalent CO response, as measured on the most sensitive CO range, which is less than one percent of full scale CO concentration on ranges above 300 ppm full scale or less than 3 ppm on ranges below 300 ppm full scale. (See §§91.317.)

(c) Alternate analytical systems. Analysis systems meeting the specifications and requirements of this subpart for dilute sampling may be used upon approval of the Administrator.

(d) Other analyzers and equipment. Other types of analyzers and equipment may be used if shown to yield equivalent results and if approved in advance by the Administrator.
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(i) The calculated flow rate, in cm³/s, (at pump inlet absolute pressure and temperature) can then be plotted versus a correlation function which is the value of a specific combination of pump parameters.

(ii) The linear equation which relates the pump flow and the correlation function is then determined.

(iii) The temperature stability must be maintained during calibration. (Flowmeters are sensitive to inlet temperature oscillations; this can cause the data points to be scattered. Gradual changes in temperature are acceptable as long as they occur over a period of several minutes.)

(iv) All connections and ducting between the flowmeter and the CVS pump must be absolutely void of leakage.

(v) The exhaust emission test measurement of these same pump parameters enables the user to calculate the flow rate from the calibration equation.

(vi) A CVS must be absolutely void of leaks, as long as they occur over a period of several minutes.

-calibration data measurements-

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Units</th>
<th>Sensor-readout tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barometric pressure (corrected)</td>
<td>P₀</td>
<td>kPa</td>
<td>±0.34 kPa</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>T₁</td>
<td>°C</td>
<td>±0.28 °C</td>
</tr>
<tr>
<td>Air temperature into metering venturi</td>
<td>T₂</td>
<td>°C</td>
<td>±1.11 °C</td>
</tr>
<tr>
<td>Pressure drop between the inlet and</td>
<td>P₁D</td>
<td>kPa</td>
<td>±0.012 kPa</td>
</tr>
<tr>
<td>throat of metering venturi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air flow</td>
<td>Q₂</td>
<td>m³/min</td>
<td>±0.5 percent of NIST value</td>
</tr>
<tr>
<td>Pressure at CVS pump inlet</td>
<td>P₂</td>
<td>kPa</td>
<td>±0.055 kPa</td>
</tr>
<tr>
<td>Pressure depression at CVS pump inlet</td>
<td>P₁D</td>
<td>kPa</td>
<td>±0.34 kPa</td>
</tr>
<tr>
<td>Pressure at CVS pump outlet (optional)</td>
<td>P₃₀</td>
<td>kPa</td>
<td>±0.055 kPa</td>
</tr>
<tr>
<td>Air temperature at CVS pump outlet</td>
<td>P₃₁</td>
<td>°C</td>
<td>±1.11 °C</td>
</tr>
<tr>
<td>Pump revolutions during test period</td>
<td>N</td>
<td>Revs</td>
<td>±1 Rev.</td>
</tr>
<tr>
<td>Elapsed time for test period</td>
<td>t</td>
<td>s</td>
<td>±0.5 s.</td>
</tr>
</tbody>
</table>

(5) After the system has been connected as shown in Figure 5 of appendix B of this subpart, set the variable restrictor in the wide open position and run the CVS pump for 30 minutes. Record the calibration data.

(6) Reset the restrictor valve to a more restricted condition in an increment of pump inlet depression that will yield a minimum of six data points for the total calibration. Allow the system to stabilize for 3 minutes and repeat the data acquisition.

(7) Data analysis:

(i) The air flow rate, Qₑ, at each test point is calculated in standard cubic feet per minute 20 °C, 101.3 kPa from the flowmeter data using the manufacturer’s prescribed method.

(ii) The air flow rate is then converted to pump flow, Vₑ, in cubic meter per revolution at absolute pump inlet temperature and pressure:

\[
V₀ = \frac{Qₑ}{n} \times \frac{Tₚ}{293} \times \frac{101.3\text{kPa}}{Pₚ}
\]

Where:

\(V₀\) = Pump flow, m³/rev at \(Tₚ, Pₚ\).
\(Qₑ\) = Meter air flow rate in standard cubic meters per minute, standard conditions are 20 °C, 101.3 kPa.
\(n\) = Pump speed in revolutions per minute.
\(Tₚ\) = Pump inlet temperature in Kelvin, = \(Pₚ+273\) °K.
\(Pₚ\) = Absolute pump inlet pressure, kPa.
\(Pₑ\) = barometric pressure, kPa.
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P_{PE} = Pump inlet depression, kPa.

(iii) The correlation function at each test point is then calculated from the calibration data:

\[ X_O = \frac{1}{n} \sqrt{\frac{\Delta P}{P_e}} \]

Where:
- \( X_O \): correlation function.
- \( \Delta P \): The pressure differential from pump inlet to pump outlet, kPa.
- \( P_e = P_e \) = Absolute pump outlet pressure, (kPa)
- \( P_{PE} = P_{PO} \)

Where:
- \( P_{PO} \): Pressure head at pump outlet, kPa (inches fluid).

(iv) A linear least squares fit is performed to generate the calibration equation which has the form:

\[ V_O = D_O + M(X_O) \]

Where:
- \( D_O \) and \( M \) are the intercept and slope constants, respectively, describing the regression line.

(8) A CVS system that has multiple speeds should be calibrated on each speed used. The calibration curves generated for the ranges will be approximately parallel and the intercept values, \( D_O \), will increase as the pump flow range decreases.

(9) If the calibration has been performed carefully, the calculated values from the equation will be within ±0.50 percent of the measured value of \( V_O \). Values of \( M \) will vary from one pump to another, but values of \( D_O \) for pumps of the same make, model and range should agree within three percent of each other. Calibrations should be performed at pump start-up and after major maintenance to assure the stability of the pump slip rate. Analysis of mass injection data will also reflect pump slip stability.

(d) CFV-CVS calibration. (1) Calibration of the CFV is based upon the flow equation for a critical venturi.

(i) Gas flow is a function of inlet pressure and temperature:

\[ Q_s = \frac{K_v P}{\sqrt{T_K}} \]

Where:
- \( Q_s \): flow rate [m³/min].
- \( K_v \): calibration coefficient.
- \( P \): absolute pressure [kPa].
- \( T_K \): absolute temperature [°K].

(ii) The calibration procedure described in paragraph (d)(3) of this section establishes the value of the calibration coefficient at measured values of pressure, temperature and air flow.

(2) The manufacturer’s recommended procedure shall be followed for calibrating electronic portions of the CFV.

(3) Measurements necessary for flow calibration are as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Units</th>
<th>Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barometric Pressure (corrected)</td>
<td>( P_b )</td>
<td>kPa</td>
<td>±0.34 kPa</td>
</tr>
<tr>
<td>Temperature into flow meter</td>
<td>( T_{bi} )</td>
<td>°C</td>
<td>±0.028 °C</td>
</tr>
<tr>
<td>Pressure drop between the inlet and</td>
<td>( P_{DP} )</td>
<td>kPa</td>
<td>±0.012 kPa</td>
</tr>
<tr>
<td>throat of metering venturi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air flow</td>
<td>( Q_o )</td>
<td>m³/min</td>
<td>±0.5 percent of NIST value</td>
</tr>
<tr>
<td>Pressure head at CVS pump outlet</td>
<td>( P_{PO} )</td>
<td>kPa</td>
<td>±0.055 kPa</td>
</tr>
<tr>
<td>Temperature at venturi inlet</td>
<td>( T_v )</td>
<td>°C</td>
<td>±2.22 °C</td>
</tr>
</tbody>
</table>

(4) Set up equipment as shown in Figure 6 in appendix B of this subpart and eliminate leaks. (Leaks between the flow measuring devices and the critical flow venturi will seriously affect the accuracy of the calibration.)

(5) Set the variable flow restrictor to the open position, start the blower, and allow the system to stabilize. Record data from all instruments.

(6) Vary the flow restrictor and make at least eight readings across the critical flow range of the venturi.

(7) Data analysis. The data recorded during the calibration are to be used in the following calculations:

(i) The air flow rate (designated as \( Q_o \)) at each test point is calculated in standard cubic feet per minute from
§ 91.425 CVS calibration frequency.

Calibrate the CVS positive displacement pump or critical flow venturi following initial installation, major maintenance or as necessary when indicated by the CVS system verification (described in §91.424(e)).

§ 91.426 Dilute emission sampling calculations.

(a) The final reported emission test results must be computed by use of the following formula:

\[ A_{wm} = \frac{\sum (W_i \times f_i)}{\sum (P_i \times f_i)} \times K_{Hi} \]

Where:
- \( A_{wm} \) = Weighted mass emission level (HC, CO, CO\(_2\), or NO\(_X\)) for a test [g/kW-hr].
- \( W_i \) = Average mass flow rate of an emission from a test engine during mode \( i \) [g/hr].
- \( WF_i \) = Weighting factor for each mode \( i \) as defined in §91.410(a).
- \( P_i \) = Gross average power generated during mode \( i \) [kW] calculated from the following equation (power for the idle mode shall always be zero for this calculation):

\[ P_i = \frac{2 \Pi \times \text{speed} \times \text{torque}}{60,000} \]

speed = average engine speed measured during mode \( i \) [rev./minute]

torque = average engine torque measured during mode \( i \) [N-m]

K_{Hi} = Humidity correction factor for mode \( i \).

This correction factor only affects calculations for NO\(_X\) and is equal to one for all other emissions. K_{Hi} is also equal to one for all two-stroke engines.

(b) The mass flow rate \( (W_i) \) of an emission for mode \( i \) is determined from the following equation:

\[ W_i = Q_i \times D \times \left( C_{D_i} - C_{B_i} \times \left(1 - \frac{1}{DF_i}\right)\right) \]

Where:
- \( Q_i \) = Volumetric flow rate of the dilute exhaust through the CVS at standard conditions [m\(^3\)/hr at STP].