produce accurate results, exact con-
formance with the drawing is not re-
quired. Additional components such as
instruments, valves, solenoids, pumps
and switches may be used to provide
additional information and coordinate
the functions of the component sys-
tems. Other components such as stub-
ners, which are not needed to maintain
accuracy in some systems, may be ex-
cluded if their exclusion is based on
good engineering judgement.

(b) Major component description. The
analytical system, Figure 4 in Appen-
dix B of this subpart, consists of a
flame ionization detector (FID) or a
heated flame ionization detector
(HFID) for the measurement of hydro-
carbons, nondispersive infrared ana-
lyzers (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 be-
fore analysis. Other types of analyzers
may be used if shown to yield equiva-
lent results and if approved in advance
by the Administrator.

(2) If CO instruments are used which
are essentially free of CO$_2$ and water
density interference, the use of the con-
trolling column may be deleted. (See
§§91.317 and 91.320.)

(3) A CO instrument will be consid-
ered to be essentially free of CO$_2$
and water vapor interference if its response
to a mixture of three percent CO$_2$ in N$_2$
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. Anal-
ysis systems meeting the specifications
and requirements of this subpart for di-
lute sampling may be used upon ap-
proval 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 ac-
curate 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) After the calibration curve has
been obtained, verification of the en-
tire system may be performed by in-
jecting a known mass of gas into the
system and comparing the mass indi-
cated by the system to the true mass
injected. An indicated error does not
necessarily mean that the calibration
is wrong, since other factors can influ-
ence the accuracy of the system (e.g.,
analyzer calibration, leaks, or HC
hangup). A verification procedure is
found in paragraph (e) of this section.

(c) PDP-CVS calibration. (1) The fol-
lowing calibration procedure outlines
the equipment, the test configuration,
and the various parameters which must
be measured to establish the flow rate
of the CVS pump.

(i) All the parameters related to the
pump are simultaneously measured
with the parameters related to a flow-
meter which is connected in series with
the pump.
§ 91.424  40 CFR Ch. I (7–1–11 Edition)

(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) In the event that a CVS has a multiple speed drive, a calibration for each range used must be performed.

(2) This calibration procedure is based on the measurement of the absolute values of the pump and flowmeter parameters that relate the flow rate at each point. Two conditions must be maintained to assure the accuracy and integrity of the calibration curve:

(i) 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.)

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

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

(4) Connect a system as shown in Figure 5 in appendix B of this subpart. Although particular types of equipment are shown, other configurations that yield equivalent results may be used if approved in advance by the Administrator. For the system indicated, the following measurements and accuracies are required:

<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>P_bar</td>
<td>kPa</td>
<td>±0.34 kPa</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>T_a</td>
<td>°C</td>
<td>±0.28 °C</td>
</tr>
<tr>
<td>Air temperature into metering venturi</td>
<td>T_V</td>
<td>°C</td>
<td>±1.11 °C</td>
</tr>
<tr>
<td>Pressure drop between the inlet and throat of metering venturi</td>
<td>P_ED</td>
<td>kPa</td>
<td>±0.05 kPa</td>
</tr>
<tr>
<td>Air flow</td>
<td>Q</td>
<td>m³/min.</td>
<td>±0.5 percent of NIST value</td>
</tr>
<tr>
<td>Air temperature at CVS pump inlet</td>
<td>T_P</td>
<td>°C</td>
<td>±1.11 °C</td>
</tr>
<tr>
<td>Pressure depression at CVS pump inlet</td>
<td>P_P</td>
<td>kPa</td>
<td>±0.06 kPa</td>
</tr>
<tr>
<td>Pressure head at CVS pump outlet</td>
<td>P_HO</td>
<td>kPa</td>
<td>±0.055 kPa</td>
</tr>
<tr>
<td>Air temperature at CVS pump outlet (optional)</td>
<td>T_P</td>
<td>°C</td>
<td>±1.1 °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, Q_a, 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, V_p, in cubic meter per revolution at absolute pump inlet temperature and pressure:

\[ V_p = \frac{Q_a \times T_p \times 101.3 \text{kPa}}{293 \times P_p} \]

Where:

- \( V_p \) = Pump flow, m³/rev at \( T_p, P_p \)
- \( Q_a \) = 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.
- \( T_p \) = Pump inlet temperature in Kelvin, \( T_p+273 \degree \text{C} \).
- \( P_p \) = Absolute pump inlet pressure, kPa.
- \( P_0 \) = Barometric pressure, kPa.
Environmental Protection Agency

§ 91.424

P_{in} = Pump inlet depression, kPa.

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

\[ X_n = \frac{1}{n} \left( \Delta P \right) \]

Where:

- \( X_n \) = correlation function.
- \( \Delta P \) = The pressure differential from pump inlet to pump outlet, kPa.
- \( P_{in} \) = Absolute pump outlet pressure, (kPa)
- \( P_{out} \) = Absolute pump outlet pressure, [kPa]
- \( P_{in} \) = 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:

\[ V_0 = D_0 - M(X_n) \]

Where:

- \( D_0 \) and \( M \) are the intercept and slope constants, respectively, describing the regression line.

(v) 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, \( D_0 \), will increase as the pump flow range decreases.

(vi) If the calibration has been performed carefully, the calculated values from the equation will be within ±0.50 percent of the measured value of \( V_0 \). Values of \( M \) will vary from one pump to another, but values of \( D_0 \) 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>Air Temperature into flow meter</td>
<td>( T_{in} )</td>
<td>°C</td>
<td>±0.28 °C</td>
</tr>
<tr>
<td>Pressure drop between the inlet and</td>
<td>( P_{ID} )</td>
<td>kPa</td>
<td>±0.012 kPa</td>
</tr>
<tr>
<td>throat of metering venturi</td>
<td></td>
<td></td>
<td>±0.5 percent of NIST value</td>
</tr>
<tr>
<td>Air flow</td>
<td>( Q_s )</td>
<td>m³/min.</td>
<td>±0.655 m³/min.</td>
</tr>
<tr>
<td>CVS inlet depression</td>
<td>( P_{in} )</td>
<td>kPa</td>
<td>±0.655 kPa</td>
</tr>
<tr>
<td>Temperature at venturi inlet</td>
<td>( T_k )</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 \( Q_s \)) at each test point is calculated in standard cubic feet per minute from
the flow meter data using the manufacturer's prescribed method.

(ii) Calculate values of the calibration coefficient for each test point:

\[ K_v = \frac{Q_{sv} \sqrt{T_v}}{P_v} \]

Where:
- \( Q_{sv} \) = Flow rate in standard cubic meter per minute, at the standard conditions of 20 °C, 101.3 kPa.
- \( T_v \) = Temperature at venturi inlet, °K.
- \( P_v \) = Pressure at venturi inlet, kPa.
- \( P_{vi} \) = Venturi inlet pressure depression, kPa.

(iii) Plot \( K_v \) as a function of venturi inlet pressure. For choked flow, \( K_v \) will have a relatively constant value. As pressure decreases (vacuum increases), the venturi becomes unchoked and \( K_v \) decreases. (See Figure 7 in appendix B of this subpart)

(iv) For a minimum of eight points in the critical region calculate an average \( K_v \) and the standard deviation.

(v) If the standard deviation exceeds 0.3 percent of the average \( K_v \), take corrective action.

(e) CVS system verification. The following "gravimetric" technique can be used to verify that the CVS and analytical instruments can accurately measure a mass of gas that has been injected into the system. (Verification can also be accomplished by constant flow metering using critical flow orifice devices.)

(1) Obtain a small cylinder that has been charged with 99.5 percent or greater propane or carbon monoxide gas (CAUTION—carbon monoxide is poisonous).

(2) Determine a reference cylinder weight to the nearest 0.01 grams.

(3) Operate the CVS in the normal manner and release a quantity of pure propane into the system during the sampling period (approximately five minutes).

(4) The calculations are performed in the normal way except in the case of propane. The density of propane (0.6109 kg/m³carbon atom is used in place of the density of exhaust hydrocarbons.

(5) The gravimetric mass is subtracted from the CVS measured mass and then divided by the gravimetric mass to determine the percent accuracy of the system.

(6) Good engineering practice requires that the cause for any discrepancy greater than ±2 percent must be found and corrected.

§ 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:

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

Where:
- \( A_{wm} \) = Weighted mass emission level (HC, CO, CO₂, or NOₓ) for a test [g/kW-hr].
- \( W_i \) = Average mass flow rate of an emission from a test engine during mode i [g/hr].
- \( P_i \) = Weighting factor for each mode i as defined in § 91.410(a).

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

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

Where:
- \( Q_i \) = Volumetric flow rate of the dilute exhaust through the CVS at standard conditions (m³/hr at STP).