



National Institute for Occupational Safety and Health
National Personal Protective Technology Laboratory
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Procedure No. RCT-APR-STP-0063

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DETERMINATION OF FACEPIECE CARBON-DIOXIDE AND OXYGEN CONCENTRATION LEVELS OF TIGHT FITTING POWERED AIR-PURIFYING RESPIRATORS WITH THE BLOWER UNIT RUNNING, STANDARD TESTING PROCEDURE (STP)

1. PURPOSE

- 1.1. This test establishes the procedure for ensuring that the facepiece concentration of carbon-dioxide and oxygen do not exceed or fall below respectively, established requirements on tight fitting, powered air-purifying respirators (PAPR) with a neck seal designed to offer personal protection against particulate and gas/vapor hazards with the blower unit running. The authority for this test is established at 42 CFR, Part 84, Subpart G, Section 84.63(a)(c)(d).
- 1.2. In use, the user exhales approximately 5% carbon dioxide into the facepiece. Most of this CO₂ exits through an exhalation valve to the external environment. The residual exhaled portion that remains in the facepiece, is rebreathed during inhalation, is the portion of primary concern, and is fundamentally the object of the test requirement and this test procedure. A small amount of CO₂ is physiologically required in order to stimulate respiration; but once concentration levels increase beyond approximately 2% CO₂, there is a sharp rise in a person's respiratory minute-volume and breathing rate. 42 CFR 84 lists the maximum permissible CO₂ concentrations for open- and closed-circuit SCBA as a function of the service time of the apparatus. Based on the maximum allowable average CO₂ concentration level allowable for SCBA and the maximum allowable levels acceptable under CE standards – the maximum acceptable inspired CO₂ concentration for a PAPR with the blower unit running is 1% and the minimum allowable O₂ concentration is 19.5%.

2. GENERAL

- 2.1. This procedure describes the “Determination of Facepiece Carbon-Dioxide and Oxygen Concentration Levels of Tight Fitting, Powered Air-Purifying Respirators, With the Blower Unit Running” in sufficient detail that a person in the appropriate technical field can conduct the test and determine whether or not the performance of the product meets the established requirement.

3. EQUIPMENT/MATERIALS

- 3.1. Scott Aviation mechanical breather with sedentary cam and solenoid valves attached.
- 3.2. Thin-walled flexible plastic reservoir with a low resistance relief valve (less than 1-inch water column).
- 3.3. Instrument-grade carbon dioxide (CO₂).

- 3.4. Instrument-grade air.
- 3.5. Two-stage regulator with control valve for CO₂ cylinder (first stage gauge with 3000 psig capacity; second stage gauge with 0 - 100 psig capacity).
- 3.6. Specialty calibration gas mixture containing 5.00% CO₂ with the balance air.
- 3.7. AEI Technologies CD-3A CO₂ gas analyzer, 0 – 15%, or equivalent
- 3.8. AEI Technologies Model P-61B CO₂ gas sensor, or equivalent
- 3.9. AEI Technologies S-3A/I Oxygen (O₂) gas analyzer, 0 – 100%, or equivalent
- 3.10. AEI Technologies Model N-22M O₂ gas sensor or equivalent
- 3.11. AEI Technologies Model R-1 Flow Control unit or vacuum pump for gas sample system, or equivalent
- 3.12. MKS Instruments Model No. 1179A618CS1BV Mass Flow Controller (MFC) for gas sample system flow control with a 5% CO₂/95% air mixture flow control range of 0 to 715 sccm, or equivalent
- 3.13. MKS Instruments Mass Flow Controller Model No. 1179A13CS1BV, or equivalent, with a Carbon Dioxide flow control range of 0 to 1000 sccm
- 3.14. MKS Instruments Mass Flow Controller Model No. 1179A24CS1BV-S, or equivalent, with an air flow control range of 0 to 15,000 sccm
- 3.15. MKS Instruments Type 247 4-Channel Power Supply Readout, or equivalent
- 3.16. Validyne Engineering Corporation Single-Channel Digital Transducer Indicator/Power Supply, Model No. CD-23-A-2-A-1-C, or equivalent
- 3.17. Validyne Engineering Corporation DP45-16 4516A3S4D Pressure Transducer, +/- 1.4 inches H₂O column measurement range, or equivalent
- 3.18. Acuity AR700-4 Laser Distance Gauge, Part No. AP7010040 or equivalent, 0 – 3.5 inches linear displacement
- 3.19. Lee LIF Series 2-Way micro-solenoid control valve, part no. LFAA1206018H

4. TESTING REQUIREMENTS AND CONDITIONS

- 4.1. Prior to beginning any testing, all measuring equipment to be used must have been calibrated in accordance with the established calibration procedure and schedule. All measuring equipment utilized for this testing must have been calibrated using a method traceable to the International System of Units (SI) when available.

5. PROCEDURE

Note: Reference Section 3 for equipment/instruments, model numbers, and manufacturers. For calibration purposes, use the manufacturers' operation and maintenance manuals.

- 5.1. Calibration of the AEI Technologies CD-3A CO₂ and S-3A/I O₂ gas analyzers will be performed as follows:
 - 5.1.1. Turn on gas sample system vacuum pump. Set the gas sample system flow rate to 450 sccm as controlled by this system's mass flow controller.
 - 5.1.2. Adjust the zero potentiometer to 0.04% for the CO₂ gas analyzer and 20.95% for the O₂ gas analyzer, as necessary.
 - 5.1.3. Administer span gas to the gas sample tube sample point via a tube that is at least three times the diameter of the gas sample tube. Use a span gas flow of at least 500 sccm. The excess span gas will flow around the inlet to the sampling point to the atmosphere in the test lab. The gas sample tube sampling point shall be inserted at least several inches into the span gas delivery tube and remain in that position throughout the CO₂ gas analyzer span check and adjustment.
 - 5.1.4. Adjust the CO₂ gas analyzer span potentiometer to the span gas concentration (normally 5.00%), as necessary.
 - 5.1.5. Remove the span gas delivery tube to allow the CO₂ and O₂ gas analyzers' outputs to decrease to and stabilize near the zero gas concentrations of 0.04% and 20.95%, respectively.
 - 5.1.6. Adequate ventilation must be present in the test area to prevent the build-up of CO₂ gas near the gas sampling point.
 - 5.1.7. Repeat steps 5.1.2 through 5.1.5 until the zero and span gas concentrations for the CO₂ gas analyzer and the zero concentration for the O₂ gas analyzer are reproducible without further adjustments being necessary.
- 5.2. Determination of the CO₂ gas analyzer/gas sample system response time will be performed as follows:
 - 5.2.1. Administer calibration gas to the gas sample tubing sampling point as controlled by the gas sample system delay solenoid valve.
 - 5.2.1.1. Operate the data recording system while activating and deactivating the gas sample system delay solenoid valve to detect the times at which the calibration gas flow is started/stopped.

- 5.2.1.2. The time required to reach 90% of the CO₂ gas analyzer span gas concentration after activation of the gas sample system delay solenoid valve is the CO₂ gas analyzer/gas sample system response time (gas sample transit time plus gas CO₂ gas analyzer response time).
- 5.2.1.3. The gas sample system response time that is determined will be used when performing test data analysis.
- 5.3. CO₂ and O₂ concentration levels in the facepiece will be determined for the largest size of a multiple size device or for a single-size device as follows:
- 5.3.1. Assemble the CO₂ Deadspace Test apparatus as indicated by the schematic shown in Fig. 1. The CO₂ pickup, O₂ pickup, and pressure transducer shall be mounted where shock and vibration are minimal. Use exactly 20 inches of 3/4 inch I.D. tubing between the headform mouth and the breathing machine "T". This length of tubing has a volume of approximately 145 cm³.
- 5.3.2. All test instruments, including the CO₂ and O₂ gas analyzers, pressure transducer, and mass flow controllers should remain powered at all times. If this is not the case, allow at least 18 hours for these instruments to reach steady state after they are powered before starting testing.
- 5.3.3. Set the air flow rate to 10.45 liters/min and the CO₂ flow rate to 550 cm³/min using these streams' respective mass flow controllers. These flow rates will provide a 5% CO₂ air mixture at the headform mouth during exhalation. The flexible bag will be kept filled with slightly more than 10.5 liters/min flow (11.0 liters/min) and minimize back pressure in the system. To maintain a 5% CO₂ concentration in the exhaled breathing gas, some slight readjustment of air and CO₂ flow rates may be necessary.
- 5.3.4. Turn on the breathing machine and let it warm-up for one minute. Set the potentiometer for 14.5 rpm on the sedentary cam. This will give a flow rate of 10.5 lpm.
- 5.3.5. A LabVIEW-based software application (or equivalent) shall be used to monitor all test parameters during testing and to record all test data needed to assess the inspired CO₂ levels of the respirator being tested.
- 5.3.6. Run a blank test, operating the equipment to produce the correct CO₂ pattern at the dummy head mouth. Record the CO₂ concentration at the mouth of the headform and all other required test parameters for at least three complete respiratory cycles using the data monitoring/recording software application. Analysis of the recorded test parameters provides the average CO₂ concentration contributed by the headform. This is a blank value which must be subtracted from the total inspired CO₂ of all facepiece and breathing apparatus tested.
- 5.3.7. Mount the facepiece to be tested on the headform. Record the CO₂ concentration at the mouth of the headform and all other required test parameters for at least

three complete respiratory cycles (see Figure 2) using the data monitoring/recording software application. Analysis of the recorded test parameters provides the average CO₂ concentration contributed by the facepiece being tested.

- 5.3.8. Remove the facepiece from the headform. Repeat the actions outlined in Section 5.3.7 two additional times, for a total of three donnings.

5.4. Data is to be analyzed as follows:

- 5.4.1. Test data is recorded at 40 Hz (every 0.025 second) by the LabVIEW software application and includes CO₂ and O₂ volume % measured at the headform mouth, facepiece resistance, and linear piston displacement. This data is downloaded into an Excel spreadsheet and plots with the three traces shown in Fig. 2 are simultaneously produced.
- 5.4.2. Prior to analyzing the test data and determining test results, the CO₂ and O₂ volume % data must be shifted back in time by the time equivalent to the gas sample system response time. This is necessary to synchronize the CO₂ and O₂ volume % data with the facepiece resistance and linear piston displacement data.
- 5.4.3. The start of the inhalation phase of a breathing cycle is determined as the point in time at which the facepiece resistance (green trace in Fig. 2) begins to drop rapidly after the piston resting phase that follows the forward piston stroke.
- 5.4.4. The start of the inhalation phase is corroborated by the piston displacement (red trace in Fig. 2). The beginning of the inhalation phase is signified as the time at which the piston begins to retract (increase in displacement) after the preceding piston resting phase. The end of the inhalation phase is signified by the start of the piston resting phase that precedes the forward piston stroke.
- 5.4.5. The duration of the inhalation phase must correspond to the time between the start and end of piston retraction. With a breathing rate of 14.5 breaths per minute, the inhalation phase is 1.70 seconds.
- 5.4.6. The inspired CO₂ level for a facepiece mounted on the headform is determined from the recorded test data as follows:

Sum the measured CO₂ volume % measurements at 0.025-second increments during the inhalation phase and divide by the number of CO₂ volume % data points (n) measured. Based on the 1.70-second inhalation phase duration, n = 68.

$$\text{Avg. Inspired CO}_2 \text{ for facepiece} = \frac{(\Sigma \text{CO}_2 \text{ volume } \%) }{n}$$

- 5.4.7. The inhalation phase for a blank CO₂ level determination starts at the last peak CO₂ volume % just prior to the rapid decrease in the CO₂ volume %.

5.4.8. The blank CO₂ level is determined from the recorded test data as follows:

Sum the measured CO₂ volume % measurements at 0.025-second increments during the inhalation phase and divide by the number of CO₂ volume % data points (n) measured.

$$\text{Avg. Blank CO}_2 = \frac{(\Sigma \text{CO}_2 \text{ volume } \%)}{n}$$

5.4.9. The inspired CO₂ level for each don of the respirator being tested is the difference between the inspired CO₂ for the facepiece and the blank CO₂ level that was measured.

$$\text{Inspired CO}_2 = \text{Avg. Inspired CO}_2 \text{ (facepiece)} - \text{Avg. Blank CO}_2$$

5.4.10. The reported inspired CO₂ level for each respirator is the minimum measured inspired CO₂ concentration level of the three dons. The reported O₂ level for each respirator is the minimum O₂ level measured during the inhalation phase (the period over which the inspired CO₂ level is assessed) of the chosen don.

6. PASS/FAIL CRITERIA

6.1. The authorization for this test is set forth in 42 CFR, Part 84, Subpart G, Section 84.63(a)(c)(d).

6.2. This test establishes the standard procedure for ensuring that:

84.63. Requirements; general -

(a) Each respirator and respirator component shall when tested by the applicant and by the Institute, meet the applicable requirements set forth in subparts H through L of this part.

(c) In addition to the minimum requirements set forth in subparts H through L of this part, the Institute reserves the right to require, as a further condition of approval, any additional requirements deemed necessary to establish the quality, effectiveness, and safety of any respirator used as protection against hazardous atmospheres.

(d) Where it is determined after receipt of an application that additional requirements will be required for approval, the Institute will notify the applicant in writing of these additional requirements, and necessary examinations, inspections, or tests, stating generally the reasons for such requirements, examinations, inspections, or tests.

6.3. The maximum allowable average carbon dioxide concentration for each sample tested shall not exceed 1.0% and the measured oxygen levels at the end of inspiration shall not fall below 19.5% (during the same measurement periods for carbon dioxide assessment) with the tight-fitting powered air purifying respirator operating with the blower unit running on fully charged batteries.

7. RECORDS/TEST SHEETS

- 7.1. Record test data in a format that shall be stored and retrievable. Data to be recorded and reported as shown in attached data sheet.

8. ATTACHMENTS

- 8.1. Figure 1. NIOSH CO₂ Deadspace Test System Schematic
8.2. Figure 2. NIOSH CO₂ Deadspace Test Data Plot
8.3. Table 1. Facepiece Carbon Dioxide or Oxygen Concentration Levels of Tight-Fitting Powered Air-Purifying Respirators with the Blower Unit Running Test Data Sheet

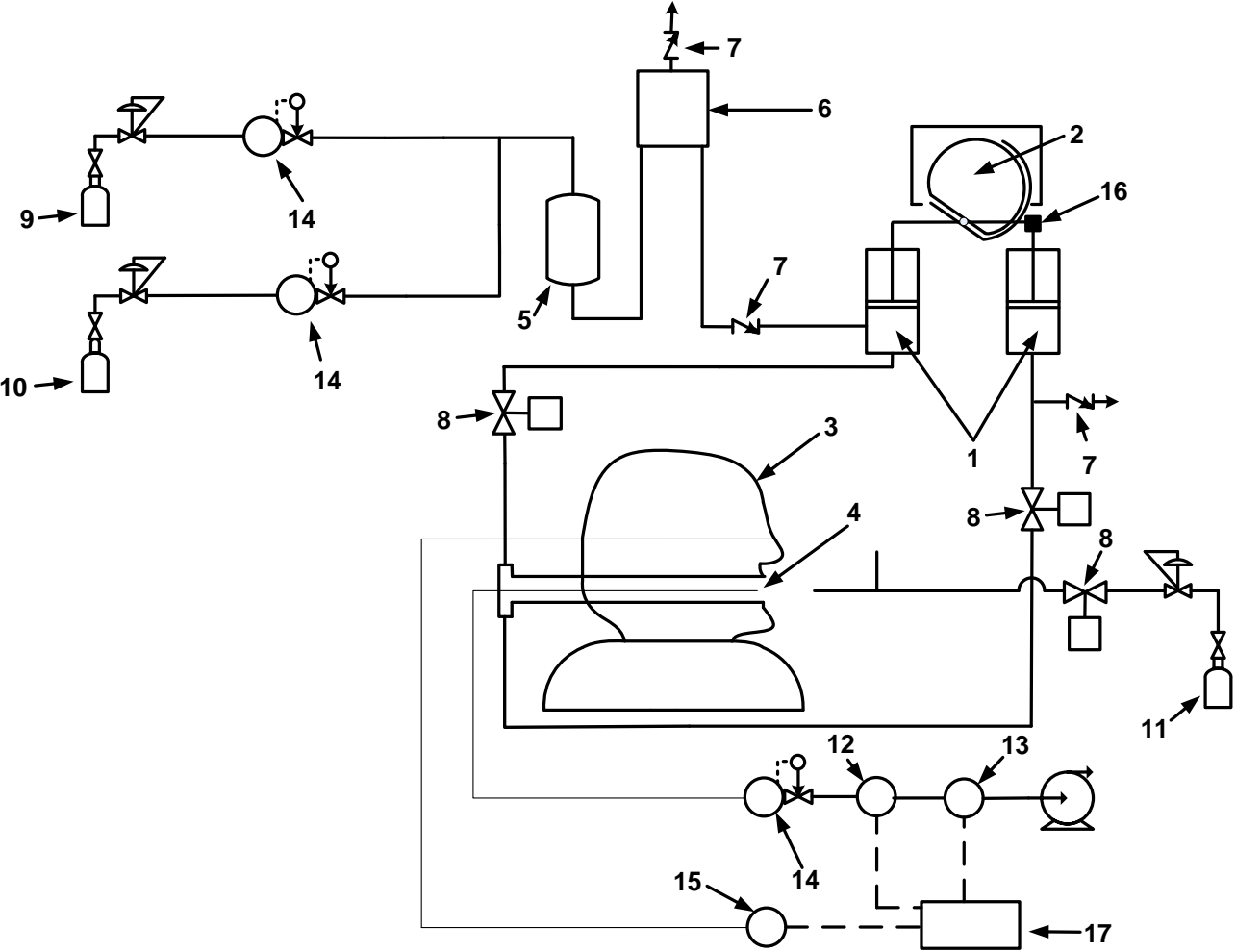


Figure 1. NIOSH CO₂ Deadspace Test System Schematic

- Key**
- 1 Breathing machine
 - 2 Sedentary cam
 - 3 Headform
 - 4 Airway opening/sampling point
 - 5 Rigid mixing vessel
 - 6 Flexible reservoir
 - 7 Non-return valve
 - 8 Solenoid valve
 - 9 CO₂ supply
 - 10 Air supply
 - 11 Calibration gas supply
 - 12 CO₂ analyzer
 - 13 O₂ analyzer
 - 14 Mass flow controller
 - 15 Pressure transducer
 - 16 Linear displacement transducer
 - 17 Computer

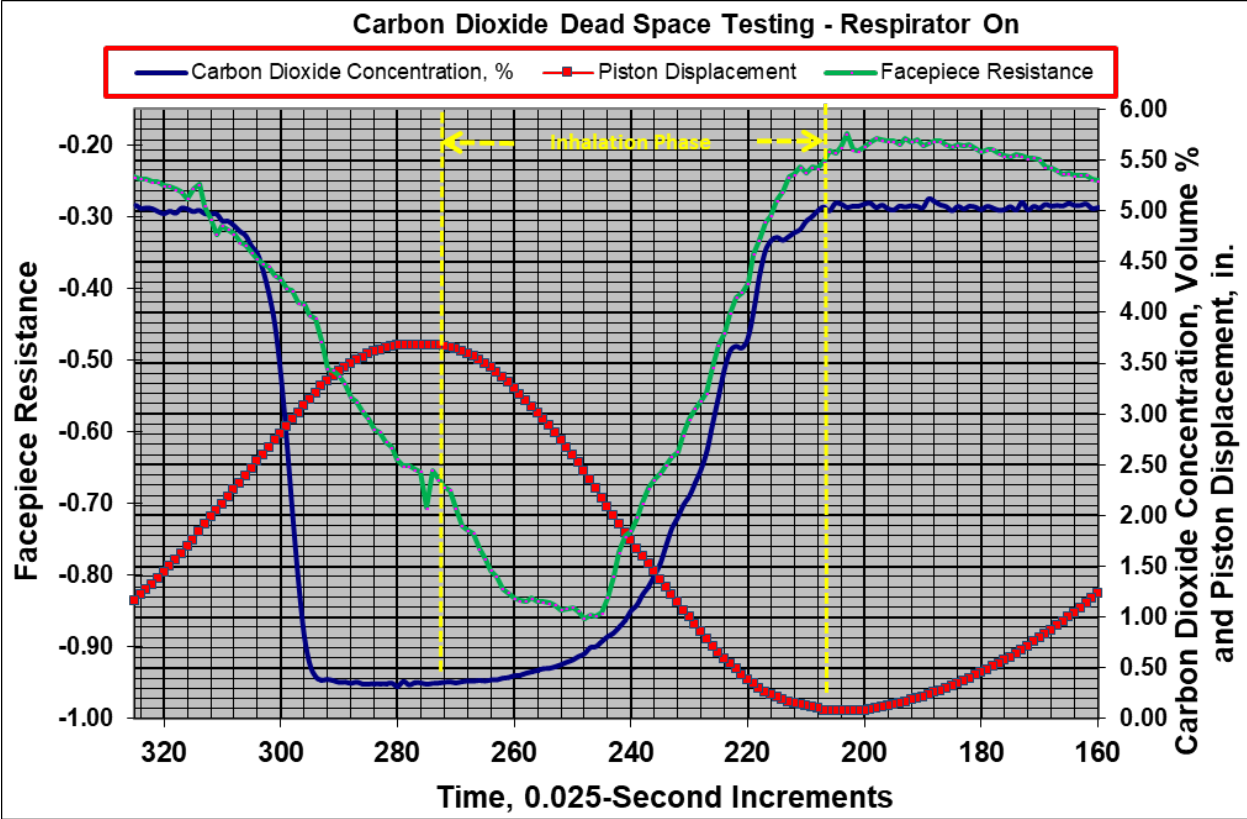


Figure 2. NIOSH CO₂ Deadspace Test Data Plot

TN -		Manufacturer:	
Facepiece or Hood	P/N:	Model No.:	
Date:		Test Technician:	

Test Data								
Event	Resp On - 1st Three Cycles			Best Three Blank Cycles				
	Trace 1	Trace 2	Trace 3	Trace 1	Trace 2	Trace 3		
4	0.00	0.00	0.00	0.00	0.00	0.00		
8	0.00	0.00	0.00	0.00	0.00	0.00		
12	0.00	0.00	0.00	0.00	0.00	0.00		
16	0.00	0.00	0.00	0.00	0.00	0.00		
20	0.00	0.00	0.00	0.00	0.00	0.00		
24	0.00	0.00	0.00	0.00	0.00	0.00		
28	0.00	0.00	0.00	0.00	0.00	0.00		
32	0.00	0.00	0.00	0.00	0.00	0.00		
36	0.00	0.00	0.00	0.00	0.00	0.00		
40	0.00	0.00	0.00	0.00	0.00	0.00		
44	0.00	0.00	0.00	0.00	0.00	0.00		
48	0.00	0.00	0.00	0.00	0.00	0.00		
52	0.00	0.00	0.00	0.00	0.00	0.00		
56	0.00	0.00	0.00	0.00	0.00	0.00		
60	0.00	0.00	0.00	0.00	0.00	0.00		
64	0.00	0.00	0.00	0.00	0.00	0.00		
68	0.00	0.00	0.00	0.00	0.00	0.00		
72	0.00	0.00	0.00	0.00	0.00	0.00		
76	0.00	0.00	0.00	0.00	0.00	0.00		
80	0.00	0.00	0.00	0.00	0.00	0.00		
# Events	0	0	0	0	0	0		
Totals	0.00	0.00	0.00	0.00	0.00	0.00		
Average	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
Average 3 Cycles -				#DIV/0!	-	#DIV/0!	=	#DIV/0!
							<u>CO2 Dead Space Level</u>	
Existing NIOSH Certification Test Method (Summary)								
# Events	0	0	0	0	0	0		
Totals	0.00	0.00	0.00	0.00	0.00	0.00		
Average	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
Average 3 Cycles -				#DIV/0!	-	#DIV/0!	=	#DIV/0!
							<u>CO2 Dead Space Level</u>	
New Data Acquisition System Method (Reported)								

Table 1. Facepiece Carbon Dioxide or Oxygen Concentration Levels of Tight-Fitting Powered Air-Purifying Respirators with the Blower Unit Running Test Data Sheet

Revision History

Revision	Date	Reason for Revision
1.0	10 December 2001	Historic document
1.1	12 September 2005	Update header and format to reflect lab move from Morgantown, WV No changes to method
2.0	5 February 2019	General update to include LabVIEW-based data monitoring, data recording and data analysis methods