National Institute for Occupational Safety and Health
National Personal Protective Technology Laboratory
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Procedure No. RCT-ASR-STP-0139	Revision: 1.1	Date: 21 September 2005

DETERMINATION OF FACEPIECE CARBON DIOXIDE CONCENTRATION LEVELS - SELF-CONTAINED BREATHING APPARATUS STANDARD TESTING PROCEDURE (STP)

1. PURPOSE

1.1. This test establishes the procedures for ensuring that the level of protection provided by the carbon dioxide concentration level requirements on Self-Contained Breathing Apparatus (SCBA) submitted for Approval, Extension of Approval, or examined during Certified Product Audits, meet the minimum certification standards set forth in 42 CFR, Part 84, Subpart G, Section 84.63(a)(c)(d), and Subpart H, Section 84.97(a)(b)(c); Volume 60, Number 110, June 8, 1995.

1.1.1. A self-contained breathing apparatus is worn when an individual is exposed to an environment immediately dangerous to life or health; which means, "conditions that pose an immediate threat to life or health or conditions that pose an immediate threat of severe exposure to contaminants which are likely to have adverse cumulative or delayed effects on health" (42 CFR, Part 84, Volume 60, Number 110, Section 84.2).

1.1.2. While wearing this apparatus, the user exhales approximately 5% carbon dioxide into the facepiece. Most of this CO_2 exits through an exhalation valve to the external environment for open-circuit apparatus or is scrubbed with a chemical scrubber and recycled for use as is the case with a closed-circuit apparatus. The residual exhaled portion that remains in the facepiece and is rebreathed during inhalation is the portion of prime concern and is the object of the test requirement and this test procedure.

1.1.3. A small amount of CO_2 is required physiologically in order to stimulate respiration; but once concentration levels increase beyond approximately 2% CO_2, there is a sharp rise in a person's respiratory minute-volume and breathing rate. Therefore, Part 84 lists the maximum permissible CO_2 concentration levels acceptable as a function of the service time of the apparatus.

1.1.4. Significant variations on a breath by breath basis for an individual prevent an accurate and reproducible determination of the average concentration levels to which he is exposed. This makes it difficult to evaluate different types of apparatus and it prevents accurate comparison among those submitted for approval.

Approvals:	1st Level	2nd Level	3rd Level

1.1.5. As a result, a machine test method was developed, using human breathing characteristics, to enable comparison between breathing apparatus, to give reproducible results, and to permit standardization on a procedure that is both accurate and reliable.

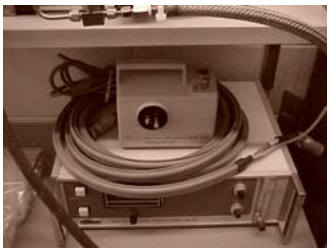
2. GENERAL

This STP describes the Determination of Facepiece Carbon Dioxide Concentration Levels - Self-Contained Breathing Apparatus test in sufficient detail that a person knowledgeable in the appropriate technical field can select equipment with the necessary resolution, conduct the test, and determine whether or not the product passes the test.

3. EQUIPMENT/MATERIALS

3.1. The list of necessary test equipment and materials follows:

3.1.1. Four Channel Thermal Tip Recording System (Model Number 7414A Hewlett Packard) with Carrier Preamplifier (Number 8805A) and Low Level Preamplifier (Model Number 8809A) or equivalent.



3.1.2. Beckman CO_2 Analyzer - Model LB2 or equivalent.

3.1.3. Mechanical Breather with Sedentary Cam and Solenoid Valves attached as shown in Figure 2. (Scott Aviation Corporation Model 23575).

3.1.4. Anthropomorphic Test head with Tubes for Measuring resistance and sampling CO_2 (Sierra Engineering Company Model 428) or equivalent.

3.1.5. Temperature Compensated Strain Sensitive Resistance Wire Type Transducer (Stratham Instruments). Pressure range $\pm$ 0.5 psig or equivalent.

3.1.6. A Thin-Walled Flexible Plastic Reservoir with a Low-Resistance Relief Valve (less than 1-inch water gauge).

3.1.7. Microcatheter Pump (0 - 100 ml per minute) (Beckman) or equivalent.

3.1.8. Flow meter Tube (F & P #2-L-150/13) - Air or equivalent.

3.1.9 Flow meter Tube (F & P #02-F 1/8-16-5/36) - CO_2 or equivalent.

3.1.10. Instrument Grade CO_2.

3.1.11. Standard CO_2 - Air Mixtures, e.g., 2%, 3%, 5% CO_2 (Matheson Gas).

3.1.12. Plant Low-Pressure Air or Positive Pressure Pump or equivalent.

3.1.13. Two Stage Regulator with Control Valve for CO_2 Cylinder. (First stage gauge with 3000 psig capacity; second stage gauge with 0 - 100 psig capacity).

3.1.14. Multiple outlet box with 6 receptacles.

3.1.15. Two jack stands.

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 manufacturer's calibration procedure and schedule. At a minimum, all measuring equipment utilized for this testing must have been calibrated within the preceding 12 months using a method traceable to the National Institute of Standards and Technology (NIST).

4.2. The compressed gas cylinder must meet all applicable Department of Transportation Requirements for cylinder approval as well as for retesting/requalification.

4.3. Normal laboratory safety practices must be observed. This includes all safety precautions described in the current ALOSH Facility Laboratory Safety Manual.

4.3.1. Safety glasses, lab coats, and hard-toe shoes must be worn during all testing.

4.3.2. Work benches must be maintained free of clutter and non-essential test equipment.

4.3.3. When handling any glass laboratory equipment, lab technicians and personnel must wear special gloves which protect against lacerations or punctures.

5. PROCEDURE

Note: Reference Section 3 for equipment, model numbers and manufacturers. For calibration purposes use those described in the manufacturer's operation and maintenance manuals.

5.1. A calibration curve is prepared using three known CO_2 - air mixtures. The volume percentages of these mixtures should be in the ranges of 2%, 3%, and 5%.

5.2. Use the manufacturer's recommended procedure for warm-up, zeroing, and operation of the CO_2 medical gas analyzer.

5.3. The lower scale of 0 to 10 divisions is to be used for a range of 0 - 5% CO_2. Feed the 5% gas mixture through the pick-up lead containing the infrared sensor at a rate of 400 cc per minute. Use the gain control for setting the scale reading to double the percent mixture or 9.90 (i.e., on a 0-10 division scale, a reading of full scale or 10 equals 5% expanded).

5.4. Then feed in the 3% and 2% gas mixtures and record the dial readings shown.

5.5. Also record the upper scale readings which have a 0 - 100 division range.

5.6. With linear graph paper, plot the upper scale readings (0 - 100 divisions) on the y-axis and the respective CO_2 % readings on the x-axis. Draw the line which best fits the points plotted for the three mixtures. See Figure 1.

5.7. If there is a noticeable drift upward with the instrument gain control setting over a period of time (i.e., day to day or month to month), it will be necessary to re-run this calibration curve.

5.8. Assemble the apparatus as shown in Figure 2. Mount the CO_2 pickup and pressure transducer where shock and vibration are minimal. Use exactly 20 inches of 3/4 inch I.D. tubing between the dummy head mouth and the breathing machine "T" (this length is critical since the response time must correlate closely with the pressure measurement for a simultaneous readout). (Tubing has a volume of 145 cc).

5.9. Allow the recorder and analyzer to warm up at least one hour.

5.10. Calibrate the pressure transducer by first balancing the carrier preamplifier as instructed in the HP manual. Set the sensitivity control to give a deflection of 2.0 cm at X1 attenuation.

5.11. Calibrate the CO_2 analyzer by first balancing the low level preamplifier as instructed in the HP manual. Set the sample flow rate at 300 - 400 cc/min. The sample flow rate

affects the response time of the analyzer. For comparison purposes, all tests must be run at the same sample flow rate. Then zero the analyzer as instructed in the HP manual. Span the analyzer with a reference gas containing slightly less than 5% CO_2, adjusting the gain control so that the meter reads the concentration of the span gas when the full scale deflection is 5% CO_2. The pressure of the reference gas going to the sample cell must not exceed atmospheric. (Use a flow of 500 cc/min of CO_2 or more. Tubing from the CO_2 gas cylinder must be at least three times the diameter of the CO_2 cell inlet port so that it is not necessary to directly connect the two. The excess CO_2 gas will then flow around the inlet port to atmospheric.) Set the low level preamplifier gain to give a corresponding recorder stylus deflection. Remove the span gas to allow the analyzer meter and recorder stylus to return to zero. If this does not occur, re-zero the analyzer and repeat the span procedure as often as necessary until zero is attained.

5.12. Adjust the air flow rate to approximately 13.00 M^3/min and the CO_2 flow rate to approximately 0.74 M^3/min. These flow rates will give a 5% CO_2 air mixture at the dummy head during exhalation. The flexible bag will be kept filled with slightly more than 10.5 l/min flow and minimize back pressure in the system. To maintain a 5% mixture, some readjustment of flow rates may be necessary.

5.13. 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.

5.14. Run a blank test, operating the equipment to produce the correct CO_2 pattern at the dummy head mouth. Record the CO_2 concentration for three complete respiratory cycles at the mouth of the dummy head. The recommended chart speed of the recorder is 10 mm/sec. Analysis of the tracing provides the average CO_2 concentration contributed by the dummy head. This is a blank value which must be subtracted from the total CO_2 in the inspired air of all facepiece and breathing apparatus tests.

5.15. For breathing apparatus tests, check the zero point on the analyzer and recorder before each test and correct for zero drift. Mount the facepiece on the dummy head. For open-circuit apparatus, connect the entire apparatus to the facepiece, place the regulator in the desired mode of operation, and open the compressed-air cylinder valve on SCBA. On the closed-circuit, only those parts contributing to dead air space are tested. Exhaled CO_2 must be released and not permitted to re-enter the closed-circuit apparatus during inhalation. Engage the breathing machine and record both the mask pressure and the CO_2 for at least three complete cycles.

5.16. Data Analysis

5.16.1. The recorder produces two traces, as shown in Figure 3. The facepiece resistance, and the CO_2 concentration at the dummy head mouth. The inhalation phase of the breathing cycle (and its duration), as determined from the facepiece resistance trace, must correspond to the inhalation portion of the CO_2 concentration trace. With a chart speed of 10 mm/sec, the inhalation phase should measure 18 or 19 mm.

5.16.2. The average concentration of inspired CO_2 is determined from the CO_2 curve as

follows: The first point on the inhalation part is the last millimeter of full scale deflection on the exhalation part of the curve. (See Figure 3.) The shaded are under the inhalation part of the trace is a measure of the inspired CO_2. Representing the time base as the x-axis, measure the deflection in the y-direction for each millimeter increment of the inhalation trace. If the inhalation cycle is 19 mm long, there will be 20 increments on the x-axis. Sum the measured deflections of the inhalation cycle and divide by the number of points (n) measured along the x-axis.

Average deflection = $(1/n)\sum$deflections.
Determine the average concentration of inspired CO_2 from the analyzer calibration curve.

6. PASS\FAIL CRITERIA

6.1. The criterion for passing this test is set forth in 42 CFR, Part 84, Subpart G, Section 84.63(a)(c)(d), and Subpart H, Section 84.97(a)(b)(c); Volume 60, Number 110, June 8, 1995.

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

84.63 Test 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.

84.97 Test for carbon dioxide in inspired gas; open- and closed-circuit apparatus; maximum allowable limits.

(a) Open-circuit apparatus:

(1) The concentration of carbon dioxide in inspired gas in open-circuit apparatus will be measured at the mouth while the apparatus mounted on a dummy head is operated by a breathing machine. An acceptable method for measuring the concentration of carbon dioxide is described in Bureau of Mines Report of Investigations 6865, A Machine-Test Method for Measuring Carbon Dioxide in the Inspired Air of Self-Contained Breathing Apparatus, 1966. Copies of Report of Investigations 6865 may be inspected or obtained from the NIOSH, Technology Evaluation Branch, 626 Cochrans Mill Road, Pittsburgh, Pennsylvania 15236.

(2) The breathing rate will be 14.5 respirations per minute with a minute-volume of 10.5 liters.

(3) A sedentary breathing machine cam will be used.

(4) The apparatus will be tested at a temperature of 27 ± 2° C. (80 ± 5° F.).

(5) A concentration of 5 percent carbon dioxide in air will be exhaled into the facepiece.

(b) Closed-circuit apparatus. The concentration of carbon dioxide in inspired gas in closed-circuit apparatus will be measured at the mouth while the parts of the apparatus contributing to dead-air space are mounted on a dummy head and operated by the breathing machine as in paragraphs (a)(1) through (5) of this section.

(c) During the testing required by paragraphs (a) and (b) of this section, the concentration of carbon dioxide in inspired gas at the mouth will be continuously recorded, and the maximum average concentration during the inhalation portion of the breathing cycle shall not exceed the following limits:

Where the service time is	Maximum allowable average concentration of carbon dioxide in inspired air percent by volume
Not more than 30 minutes.....	2.5
1 hour.....	2.0
2 hours.....	1.5
3 hours.....	1.0
4 hours.....	1.0

7. RECORDS\TEST SHEETS

7.1. All test data will be recorded on the CARBON DIOXIDE MACHINE TEST - CO_2 DEADSPACE, SELF-CONTAINED BREATHING APPARATUS test data sheet.

7.2. All videotapes and photographs of the actual test being performed, or of the tested equipment shall be maintained in the task file as part of the permanent record.

7.3. All equipment failing any portion of this test will be handled as follows;

7.3.1. If the failure occurs on a new certification application, or extension of approval application, send a test report to the RCT Leader and prepare the hardware for

return to the manufacturer.

7.3.2. If the failure occurs on hardware examined under an Off-the-Shelf Audit the hardware will be examined by a technician and the RCT Leader for cause. All equipment failing any portion of this test may be sent to the manufacturer for examination and then returned to NIOSH. However, the hardware tested shall be held at the testing laboratory until authorized for release by the RCT Leader, or his designee, following the standard operating procedures outlined in Procedure for Scheduling, and Processing Post-Certification Product Audits, RB-SOP-0005-00.

CARBON DIOXIDE MACHINE TEST - CO_2 DEADSPACE,
SELF-CONTAINED BREATHING APPARATUS

Project No : _____ Date: _____

Company : _____

Respirator Type: _____

Reference: 42 CFR, Part 84, Subpart H, Section 84.97(a)(b)(c).

Requirement: Shall not exceed maximum limits in paragraph c.

Results:

Comments:

_____

_____

_____

_____

_____

Test Engineer: _____ PASS_____ FAIL_____

CO_2 Machine Test

	BLANK				TRACE - CO_2 / INHALATION				REMARKS
MM	#1	#2	#3		#1	#2	#3		
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
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16									
17									
18									
19									
20									
TOTALS									
AVERAG									
CO_2 %									

Figure 1.

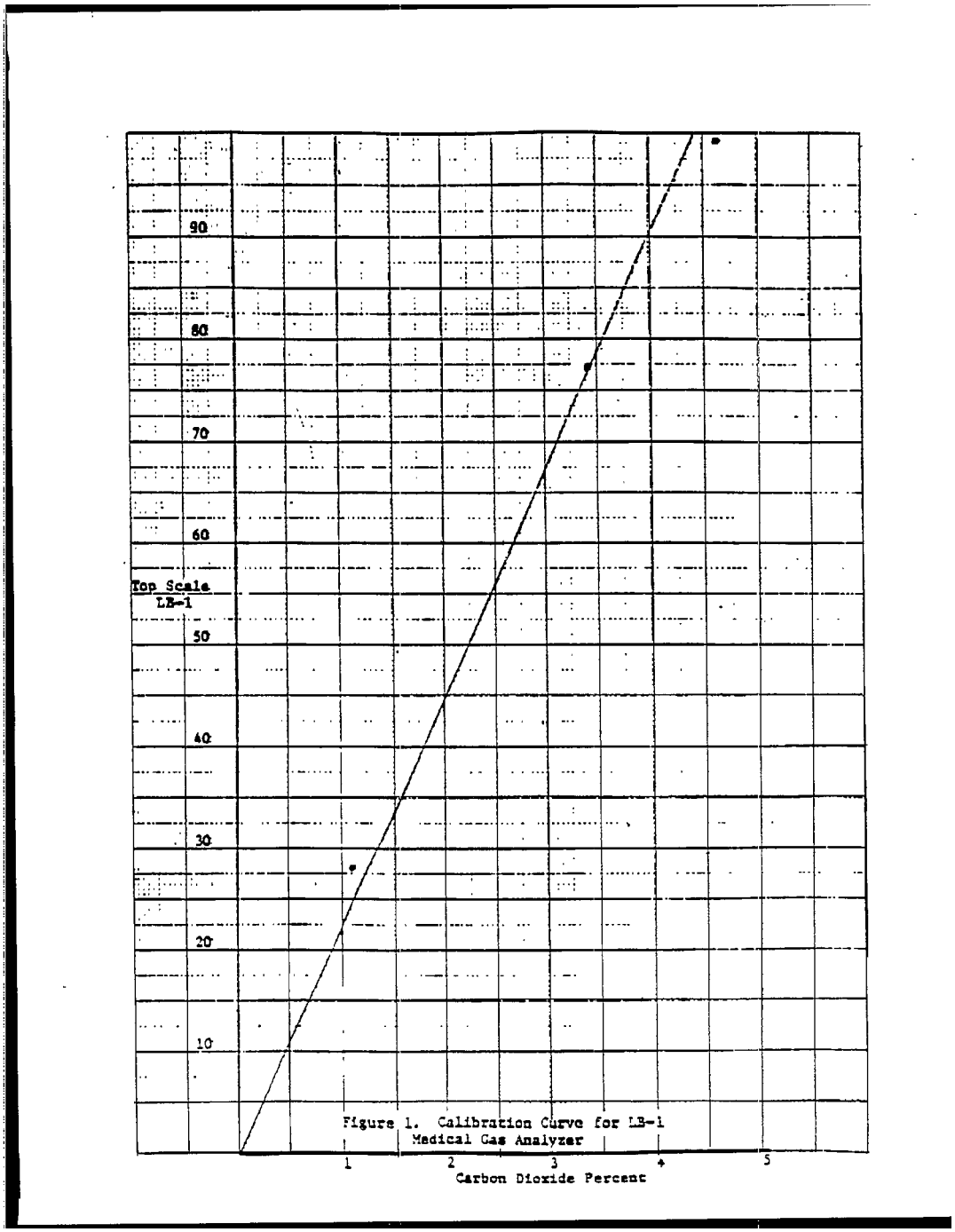


Figure 1. Calibration Curve for LB-1
Medical Gas Analyzer

Figure 2.

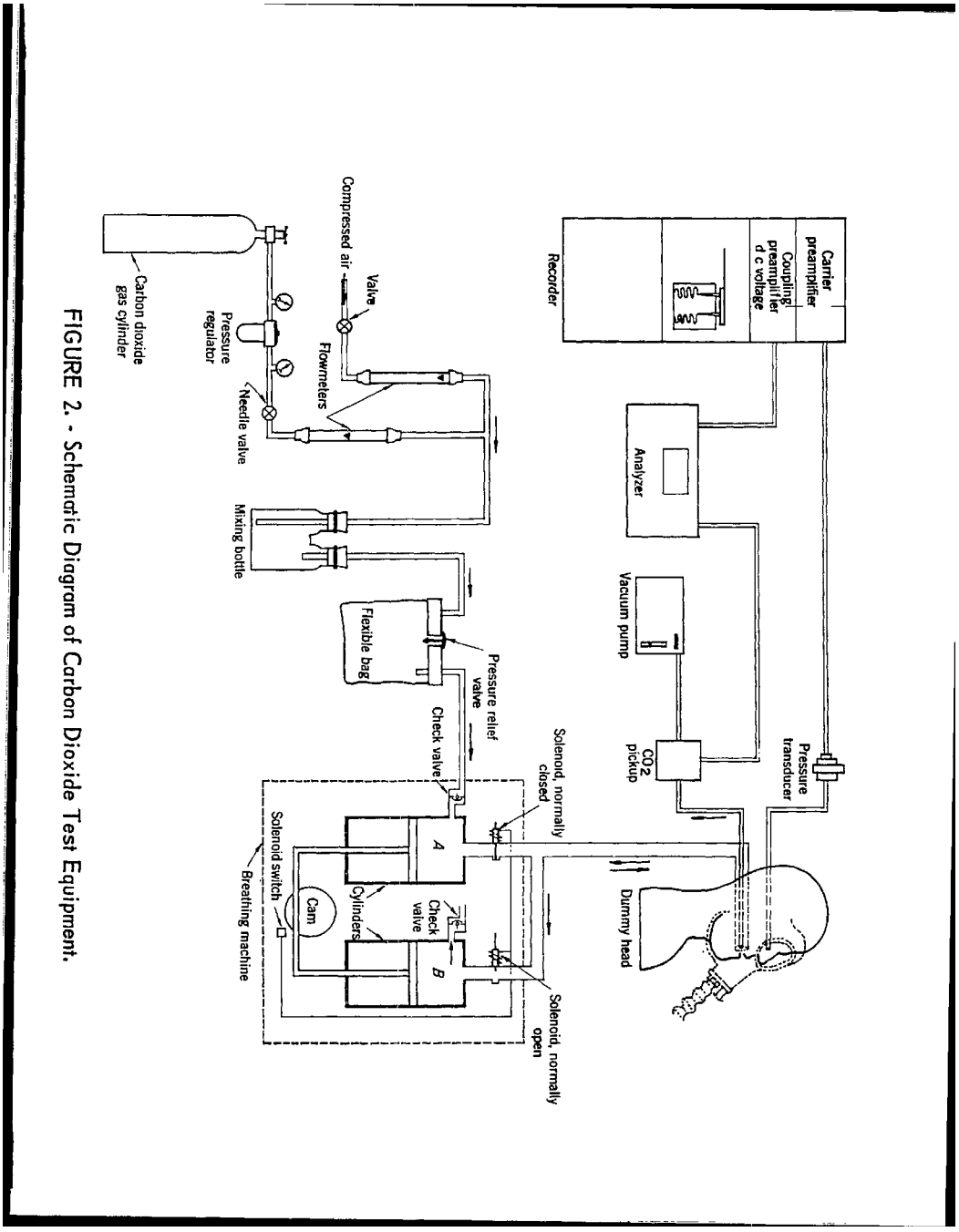
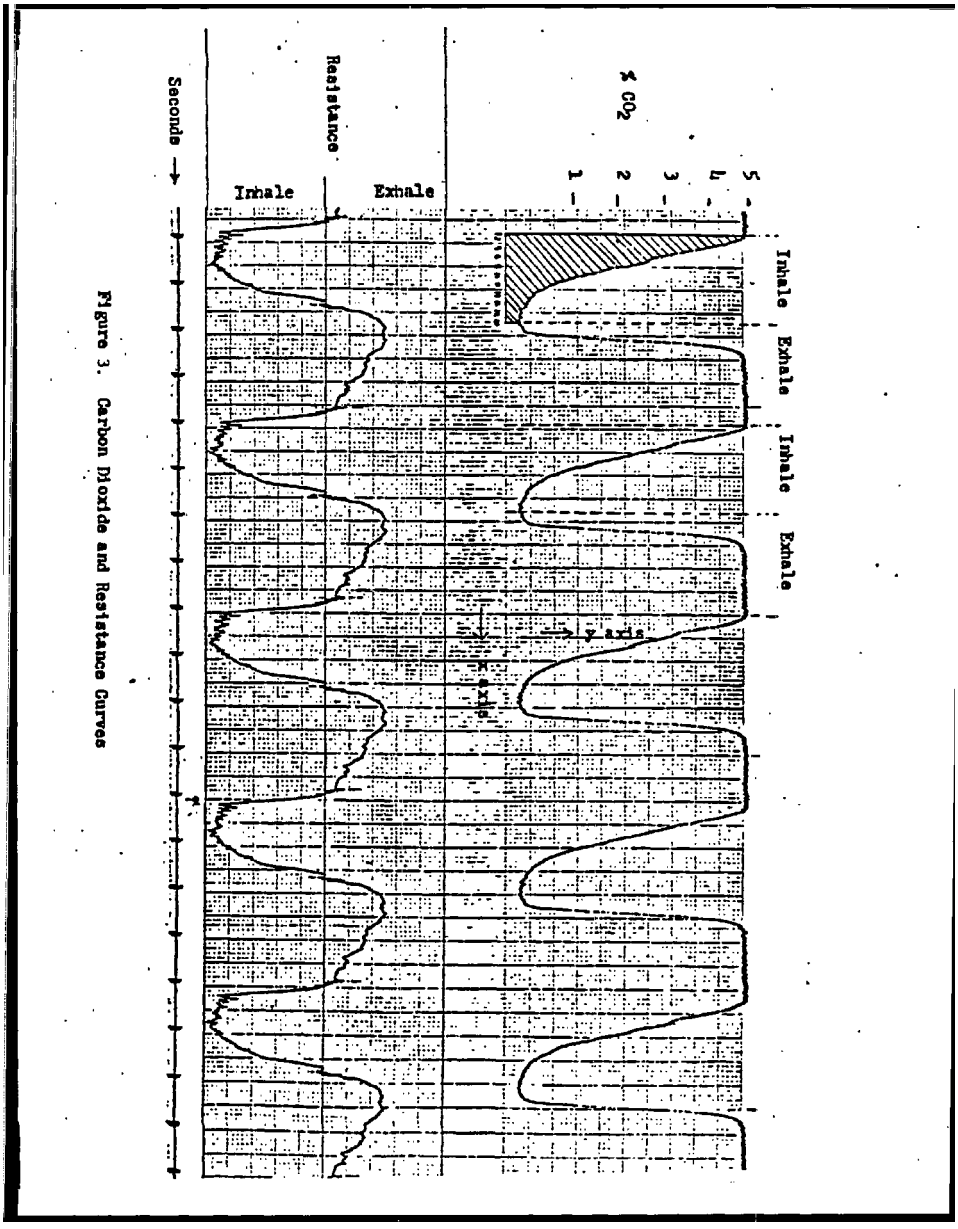
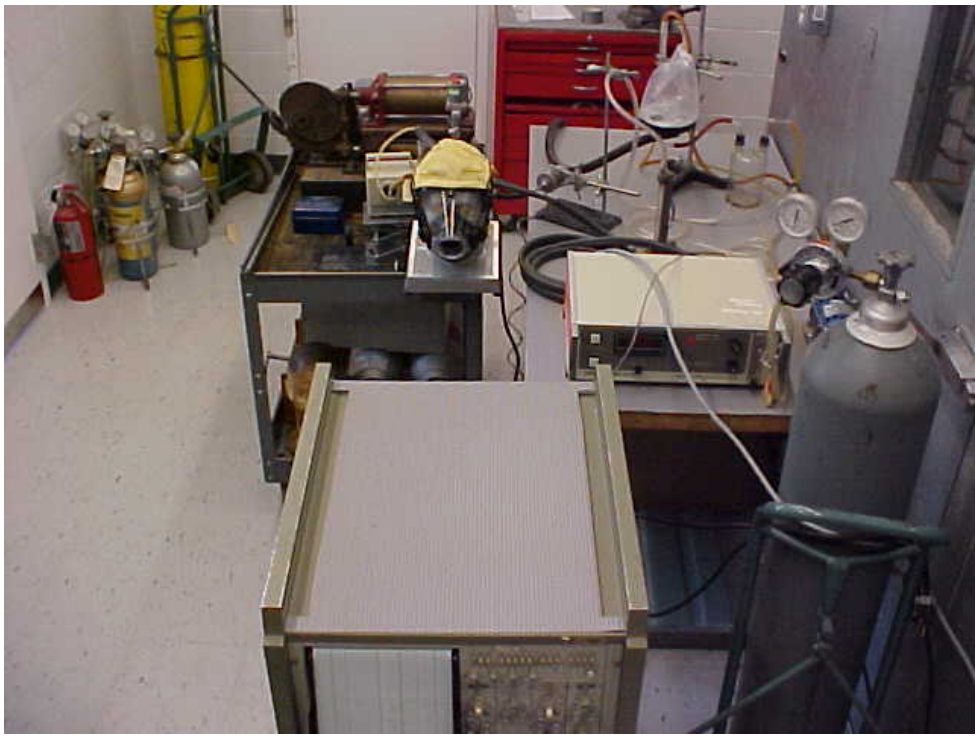
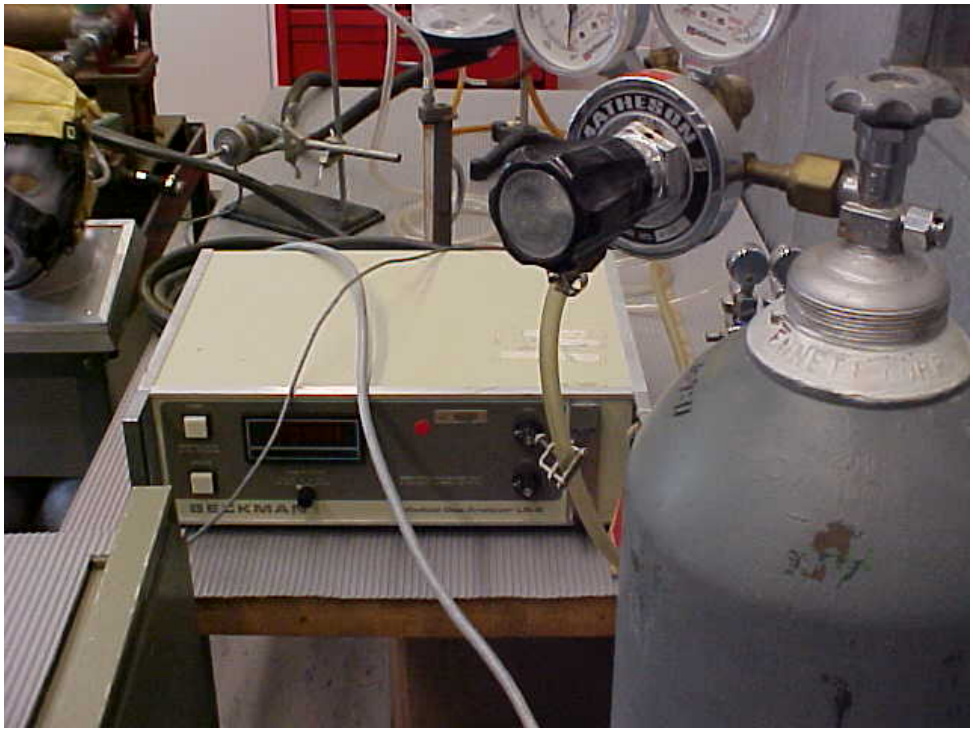


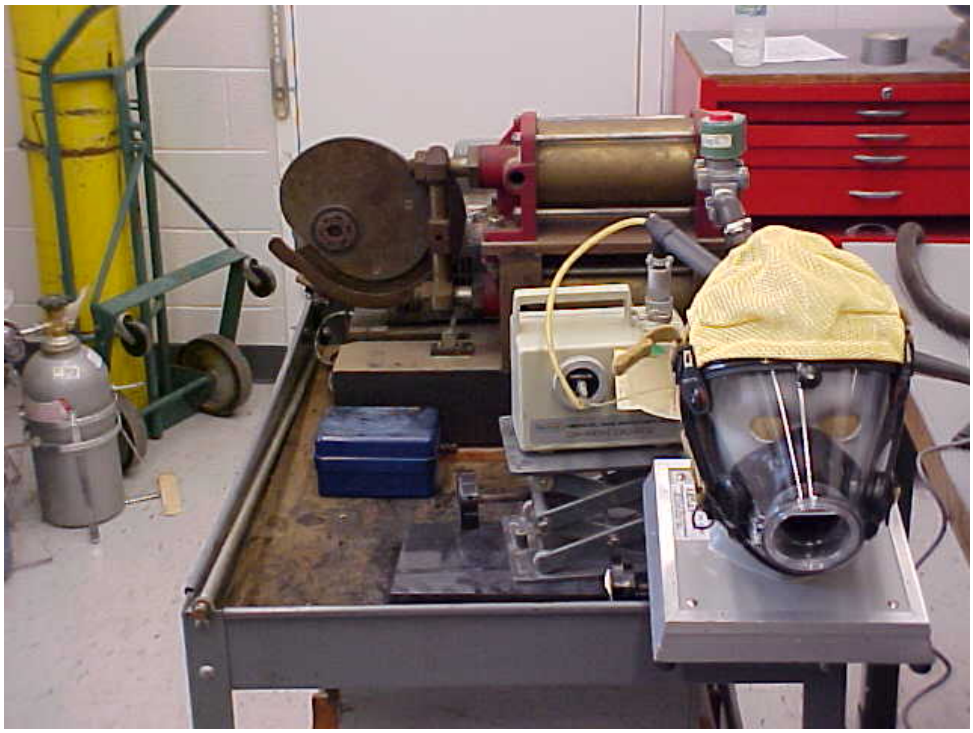
FIGURE 2. - Schematic Diagram of Carbon Dioxide Test Equipment.

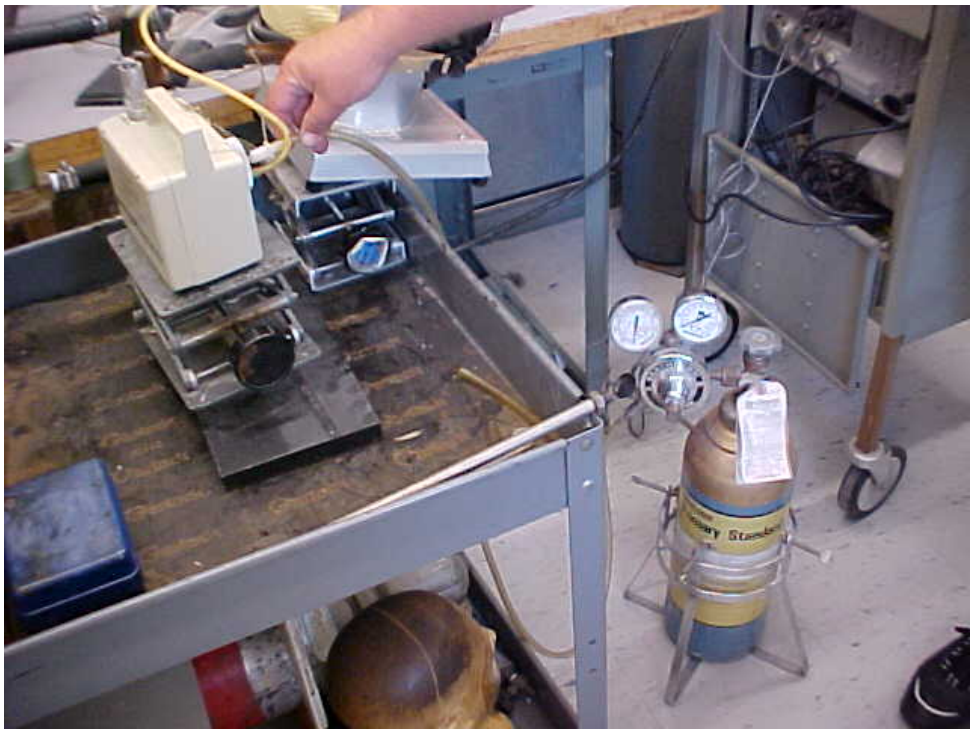
Figure 3.

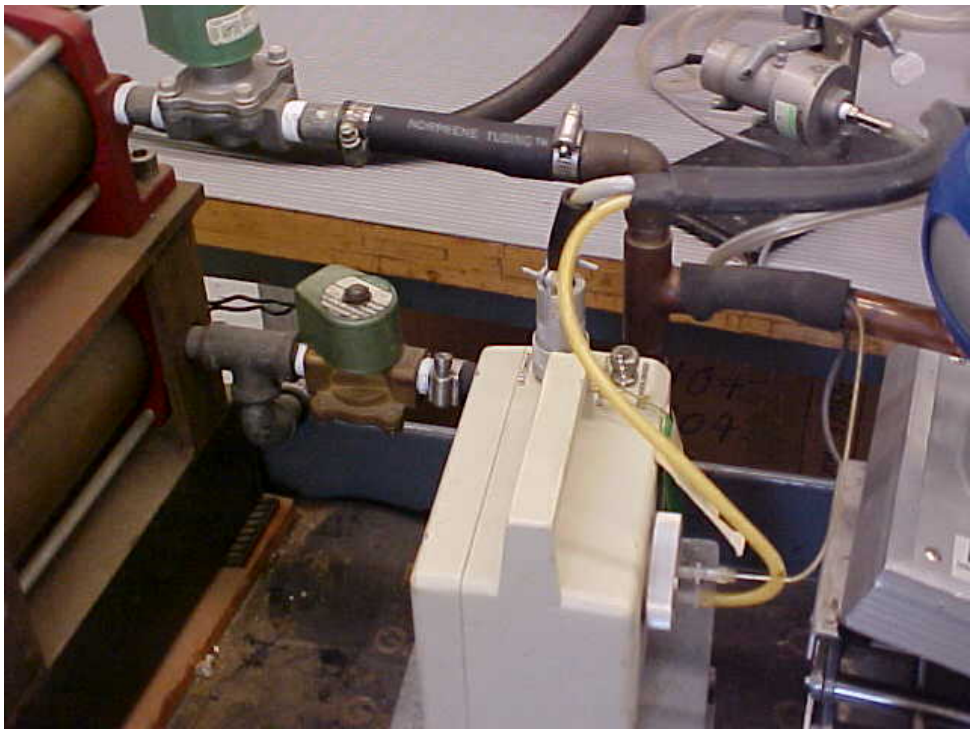

Seconds →
Resistance
Inhale
Exhale
% CO_2
1
2
3
4
5
Inhale
Exhale
Inhale
Exhale
Y axis
X axis
Figure 3. Carbon Dioxide and Resistance Curves

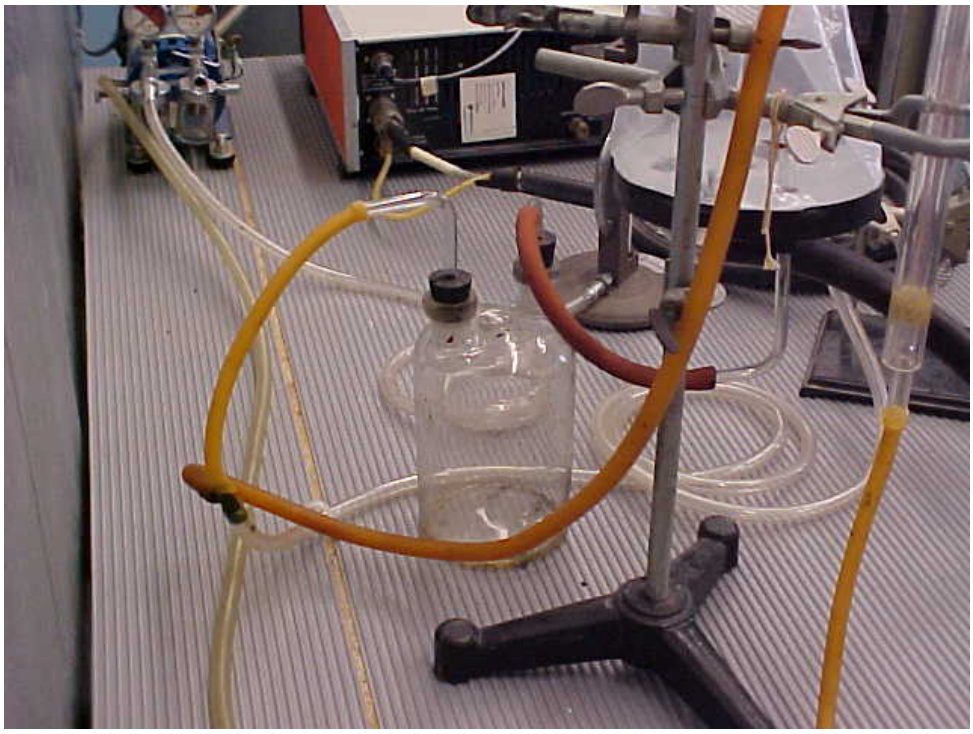


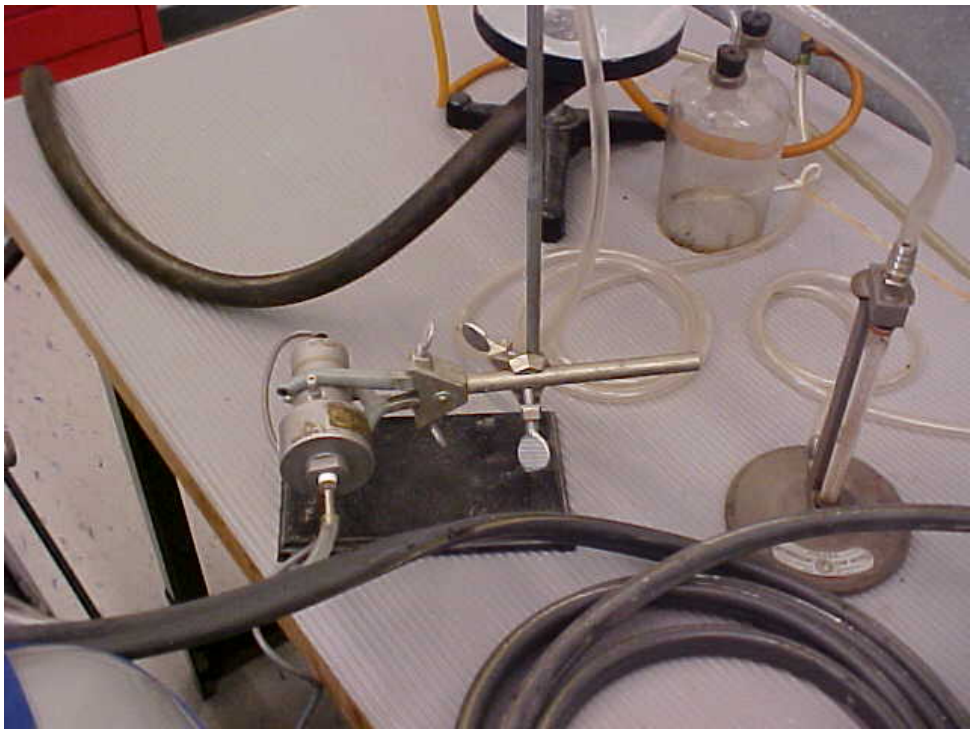

ATHESON

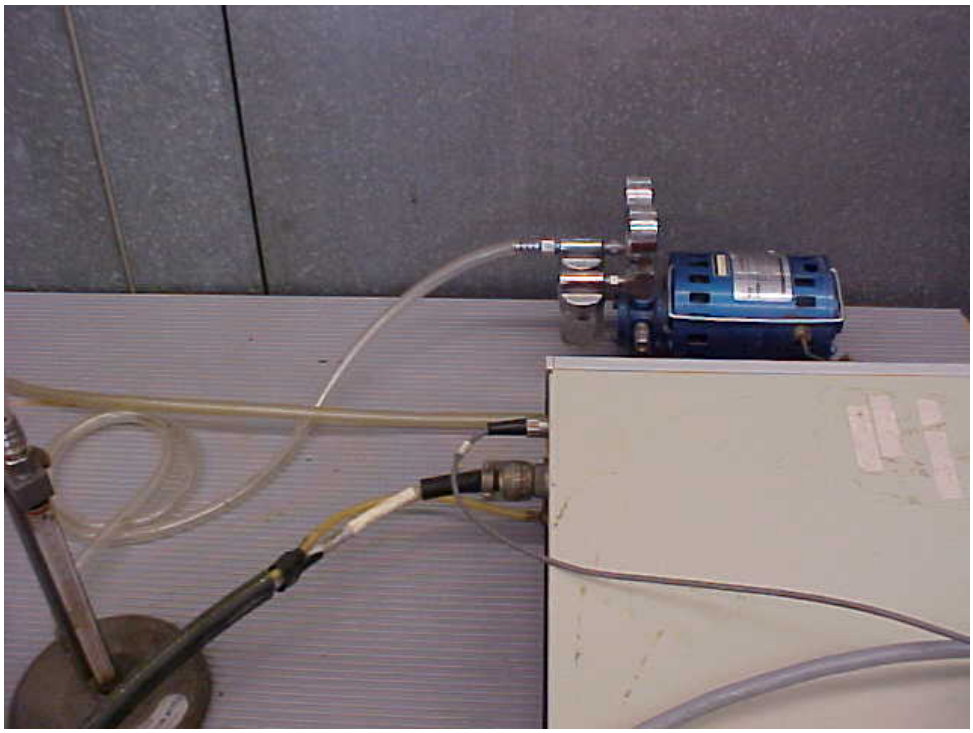


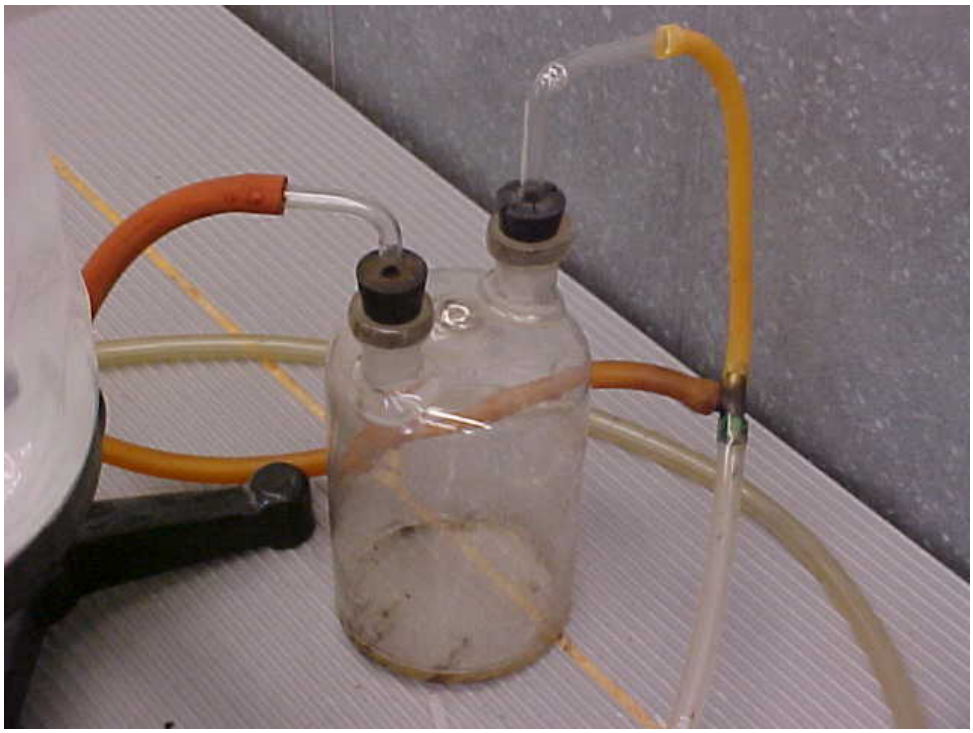


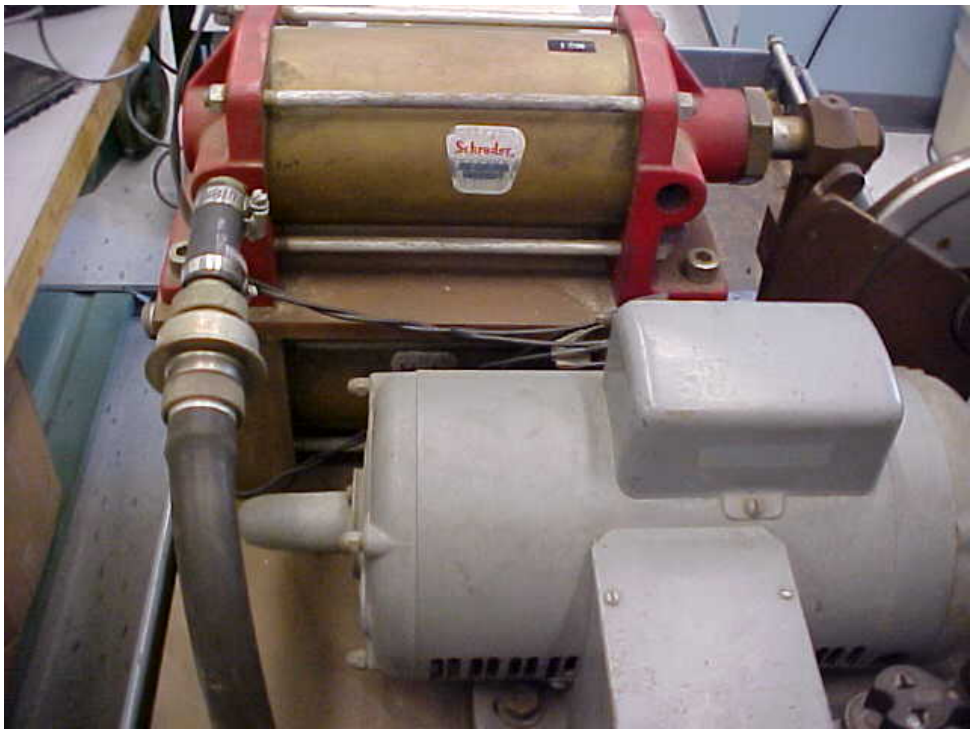


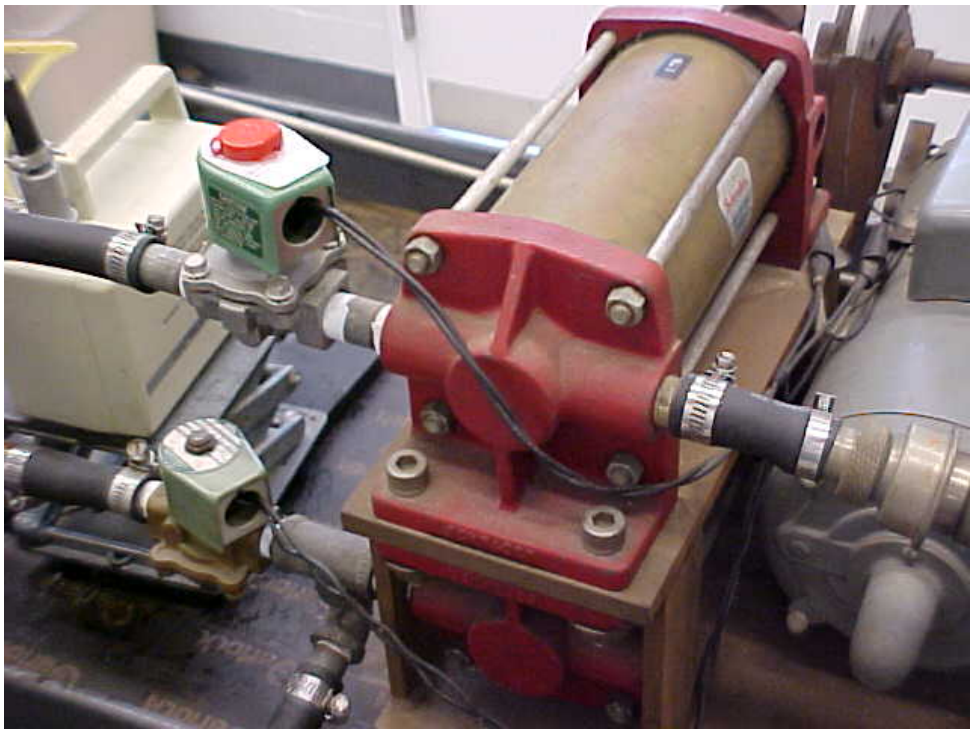









Schrader



Revision History

Revision	Date	Reason for Revision
1.0	15 February 2001	Historic document
1.1	21 September 2005	Update header and format to reflect lab move from Morgantown, WV No changes to method