CHAPTER 16

Breathing Gas Mixing Procedures

16-1 INTRODUCTION

16-1.1 **Purpose.** The purpose of this chapter is to familiarize divers with the techniques used to mix divers' breathing gas.

16-1.2 **Scope.** This chapter outlines the procedures used in mixing divers' breathing and treatment gas.

16-2 MIXING PROCEDURES

Two or more pure gases, or gas mixtures, may be combined by a variety of techniques to form a final mixture of predetermined composition. This section discusses the techniques for mixing gases. Aboard ships, where space is limited and motion can affect the accuracy of precision scales, gases are normally mixed by partial pressure or by continuous-flow mixing systems. The methods of mixing by volume or weight are most suitable for use in shore-based facilities because the procedure requires large, gas-tight holding tanks and precision scales.

16-2.1 **Mixing by Partial Pressure.** Mixing gases in proportion to their partial pressures in the final mixture is the method commonly used at most Navy facilities. The basic principle behind this method is Dalton's Law of Partial Pressures, which states that the total pressure of a mixture is equal to the sum of the partial pressures of all the gases in the mixture.

The partial pressure of a gas in a mixture can be calculated using the ideal-gas (perfect-gas) method or the real-gas method. The ideal-gas method assumes that pressure is directly proportional to the temperature and density of a gas. The real-gas method additionally accounts for the fact that some gases will compress more or less than other gases.

Compressibility is a physical property of every gas. Helium does not compress as much as oxygen.

If two cylinders with the same internal volume are filled to the same pressure, one with oxygen and the other with helium, the oxygen cylinder will hold more cubic feet of gas than the helium cylinder. As pressure is increased, and/or as temperature is decreased in both cylinders, the relative difference in the amount of gas in each cylinder increases accordingly. The same phenomenon results when two gases are mixed in one cylinder. If an empty cylinder is filled to 1,000 psia with oxygen and topped off to 2,000 psia with helium, the resulting mixture contains more oxygen than helium.

Being aware of the differences in the compressibility of various gases is usually sufficient to avoid the problems that are often encountered when mixing gases.

When using the ideal-gas procedures, a diver should add less oxygen than is called for, analyze the resulting mixture, and compensate as required. The *U.S. Navy Diving-Gas Manual* (NAVSEA 0994-LP-003-7010, June 1971) should be consulted for procedures to accurately calculate the partial pressures of each gas in the final mixture. These procedures take into consideration the compressibility of the gases being mixed. Regardless of the basis of the calculations used to determine the final partial pressures of the constituent gases, the mixture shall always be analyzed for oxygen content prior to use.

16-2.2 **Ideal-Gas Method Mixing Procedure.** Gas mixing may be prepared one cylinder at a time or to and from multiple cylinders. The required equipment is inert gas, oxygen, mix cylinders or flasks, an oxygen analyzer, and a mixing manifold. A gas transfer system may or may not be used. Typical mixing arrangements are shown in Figure 16-1 and Figure 16-2. To mix gas using the idea-gas method:

1. Measure the pressure in the inert-gas cylinder(s) P_I.

2. Calculate the pressure in the mixed-gas cylinder(s) after mixing, using the following equation:

$$P_F = \frac{P_I + 14.7}{A} - 14.7$$

Where:
P_F = Final mix cylinder pressure, psig*
P_I = Inert gas cylinder pressure, psig
A = Decimal percent of inert gas in the final mixture

* PF cannot exceed the working pressure of the inert gas cylinder.

3. Measure the pressure in the oxygen cylinder(s), P_o.

4. Determine if there is sufficient pressure in the oxygen cylinder(s) to accomplish mixing with or without an oxygen transfer pump.

$$P_O \geq (2P_F - P_I) + 50$$

Where:
P_O = Pressure in the oxygen cylinder, psig
50 = Required minimum over pressure, psi
≥ *means* greater than or equal to

5. Connect the inert-gas and oxygen cylinder(s) using an arrangement shown in Figure 16-1 or Figure 16-2.

6. Open the mix gas cylinders valve(s).

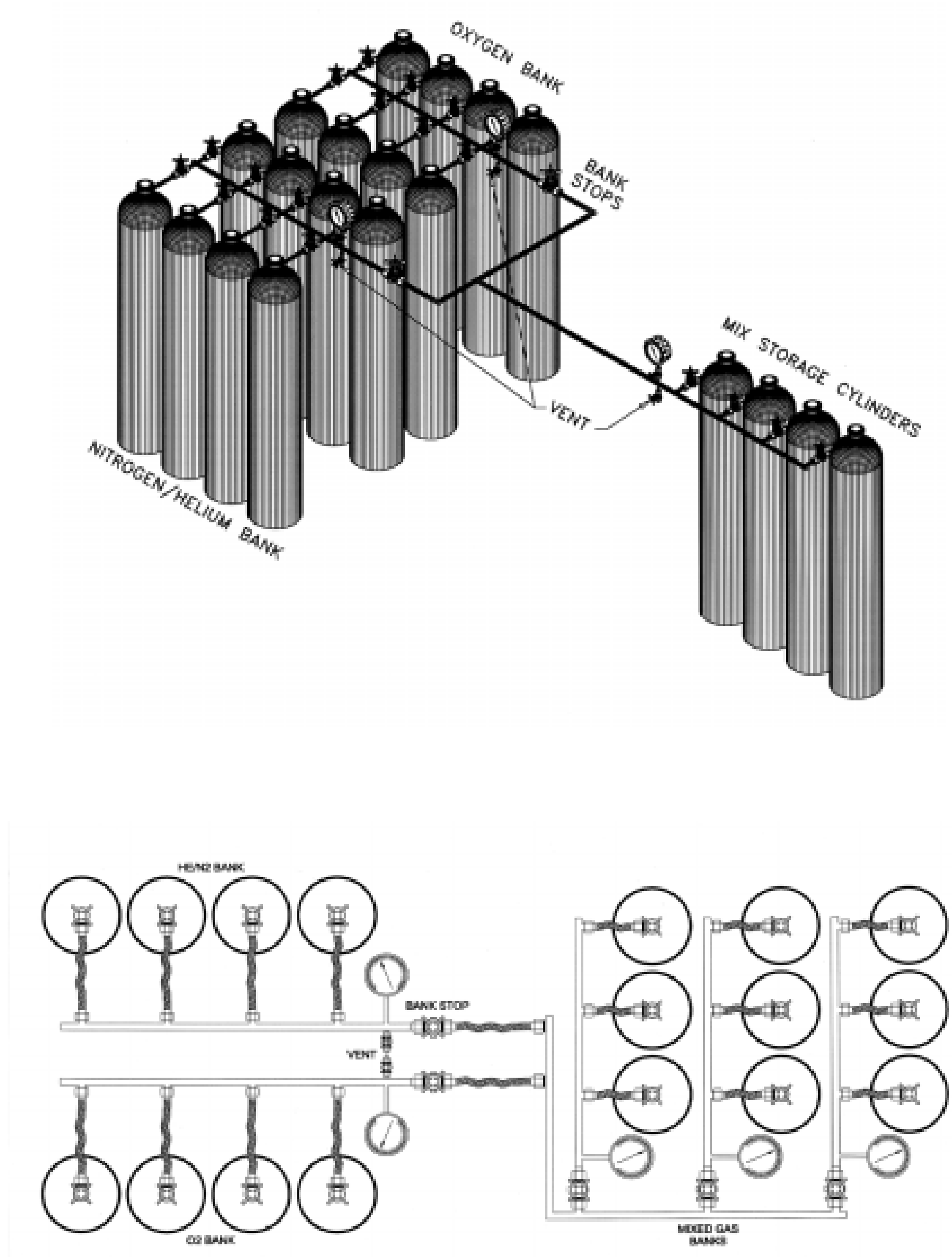

Figure 16-1. Mixing by Cascading.

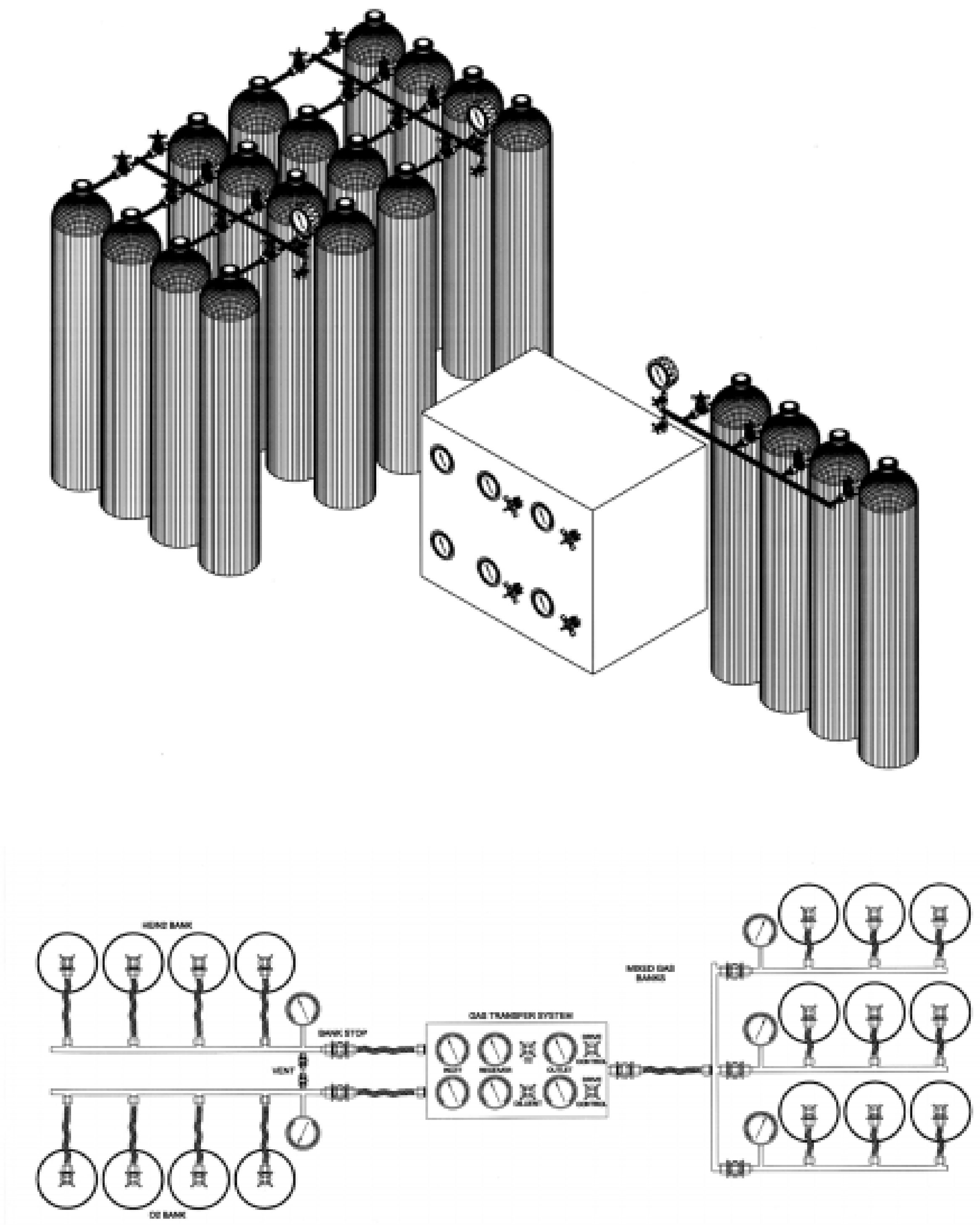

Figure 16-2. Mixing with Gas Transfer System.

7. Open the oxygen cylinders valve. Bleed oxygen into the mix gas cylinders at a maximum rate of 70 psi minute until the desired P_F is reached.

8. Close the oxygen and mixed-gas cylinder valves. The heat of compression will have increased the temperature of the mixed-gas cylinders and will give a false indication of the pressure in the cylinder. The calculation requires the P_F to be taken at the same temperature as P_I. However, because of the compressibility effects, more oxygen will normally have to be bled into the mixed-gas cylinders than expected. Therefore, allow the cylinders to stand for at least six hours to permit the gases to mix homogeneously, or if equipment is available, roll the cylinder for at least one hour. Analyze the gas mixture to determine its oxygen percentage. The percentage of oxygen should be near or slightly below the desired percentage.

9. Add oxygen as necessary and reanalyze the mixture. Repeat this step until the desired mixture is attained.

16-2.3 **Adjustment of Oxygen Percentage.** After filling a mixed-gas cylinder, it may be necessary to increase or decrease the percentage of oxygen in the cylinder.

16-2.3.1 **Increasing the Oxygen Percentage.** To increase the oxygen percentage:

1. Subtract the known percentage of oxygen from 100 to obtain the existing percentage of helium.

2. Multiply the helium percentage by the cylinder pressure to obtain the pressure of helium in the cylinder.

3. Subtract the desired oxygen percentage from 100 to obtain the desired percentage of helium.

4. Divide the existing helium pressure (Step 2) by the desired helium percentage (Step 3) in decimal form. (This step gives the cylinder pressure that will exist when enough oxygen has been added to yield the desired percentage.)

5. Add oxygen until this pressure is reached.

6. Allow temperature and pressure to stabilize and add more oxygen, if necessary.

The following formula sums up the computation:

$$F = \frac{P \times (1.00 - O_o)}{(1.00 - O_f)}$$

Where:

F = Final cylinder pressure
P = Original Cylinder pressure
O_o = Original oxygen % (decimal form)
O_f = Final oxygen % (decimal form)

Sample Problem. An oxygen cylinder contains 1,000 psi of a 16 percent oxygen mixture, and a 20 percent oxygen mixture is desired.

$$F = \frac{1,000 \times (1.00 - 0.16)}{1.00 - 0.20}$$
$$= \frac{1,000 \times 84}{0.80}$$
$$= \frac{840}{0.80}$$
$$= 1,050 \text{ psi}$$

Add 50 psi of oxygen to obtain a cylinder pressure of 1,050 psi.

16-2.3.2 **Reducing the Oxygen Percentage.** To reduce the oxygen percentage, use the following procedure:

1. Multiply oxygen percentage (decimal form) by the cylinder pressure to obtain the psi of oxygen pressure.
2. Divide this figure by the desired oxygen percentage (decimal form). This yields the final pressure to be obtained by adding helium.
3. Add helium until this pressure is reached.
4. Allow temperature and pressure to stabilize and add more helium, if necessary.

The following formula sums up the computation:

$$F = \frac{P \times O_o}{O_f}$$

Where:

F = Final cylinder pressure
P = Original Cylinder pressure
O_o = Original oxygen % (decimal form)
O_f = Final oxygen % (decimal form)

Sample Problem. For a cylinder containing 1,000 psi of a 20 percent oxygen mixture and a 16 percent oxygen mixture is desired.

$$F = \frac{1,000 \times 0.20}{0.16}$$

$$= \frac{200}{0.16}$$

$$= 1,250 \text{ psi}$$

Add 250 psi of helium to obtain a cylinder pressure of 1,250 psi.

These mixing procedures also apply to mixing by means of an oxygen-transfer pump. Instead of being bled directly from an oxygen cylinder into a helium cylinder, oxygen may be drawn from a cylinder at low pressure by the oxygen-transfer pump until the proper cylinder pressure is reached. This allows most of the oxygen in the cylinder to be used, and it also conserves gas.

16-2.4 **Continuous-Flow Mixing.** Continuous-flow mixing is a precalibrated mixing system that proportions the amounts of each gas in a mixture by controlling the flow of each gas as it is delivered to a common mixing chamber. Continuous-flow gas mixing systems perform a series of functions that ensure extremely accurate mixtures. Constituent gases are regulated to the same pressure and temperature before they are metered through precision micro-metering valves. The valve settings are precalibrated and displayed on curves that are provided with every system and relate final mixture percentages with valve settings. After mixing, the mixture is analyzed on-line to provide a continuous history of the oxygen percentage. Many systems have feedback controls that automatically adjust the valve settings when the oxygen percentage of the mixture varies from preset tolerance limits. The final mixture may be supplied directly to a diver or a chamber or be compressed into storage tanks for later use.

16-2.5 **Mixing by Volume.** Mixing by volume is a technique where known volumes of each gas are delivered to a constant-pressure gas holder at near-atmospheric pressure. The final mixture is subsequently compressed into high-pressure cylinders. Mixing by volume requires accurate gas meters for measuring the volume of each gas added to the mixture. When preparing mixtures with this technique, the gases being mixed shall be at the same temperature unless the gas meters are temperature compensated.

The volumes of each of the constituent gases are calculated based on their desired percentages in the final mixture. For example, if 1,000 scf of a 90 percent helium/10 percent oxygen mixture is needed, 900 scf of helium will be added to 100 scf of oxygen. Normally, an inflatable bag large enough to contain the required volume of gas at near-atmospheric pressure is used as the mixing chamber. The pure gases, which are initially contained in high-pressure cylinders, are regulated at atmospheric pressure, metered, and then piped into the mixing chamber. Finally, the mixture is compressed and stored in high-pressure flasks or cylinders.

Provided that the temperatures of the constituent gases are essentially the same, extremely accurate mixtures are possible by using the volume technique of mixing. Additionally, care must be taken to ensure that the mixing chamber is either completely empty or has been filled with a known mixture of uncontaminated gas before mixing.

16-2.6 **Mixing by Weight.** Mixing by weight is most often employed where small, portable cylinders are used. This proportions the gases in the final mixture by the weight that each gas adds to the initial weight of the container. When mixing by weight, the empty weight of the container must be known as well as the weight of any gases already inside the container. The weight of each gas to be added to the container must be calculated using the procedures described in the *U.S. Navy Diving-Gas Manual*. Although the accuracy of the mixture when using this technique is not affected by variations in gas temperature, it is directly dependent on the accuracy of the scale being used to weigh the gases. This accuracy shall be known and the operator must be aware of its effect on the accuracy of the composition of the final mixture. As a safeguard, the final mixture must be analyzed for composition using an accurate method of analysis.

16-3 GAS ANALYSIS

The precise determination of the type and concentration of the constituents of breathing gas is of vital importance in many diving operations. Adverse physiological reactions can occur when exposure time and concentrations of various components in the breathing atmosphere vary from prescribed limits. Analysis of oxygen content of helium-oxygen mixtures shall be accurate to within ± 0.5 percent.

The quality of the breathing gas is important in both air and mixed-gas diving. In air diving, the basic gas composition is fixed, and the primary consideration is directed toward determining if gaseous impurities are present in the air supply (i.e. carbon monoxide, hydrocarbons) and the effects of inadequate ventilation (carbon dioxide). Using analytical equipment in air diving is not routine practice. Analytical equipment is generally employed only when it is suspected that the air supply is not functioning properly or when evaluating new equipment.

Gas analysis is essential in mixed-gas diving. Because of the potential hazards presented by anoxia and by CNS and pulmonary oxygen toxicity, it is mandatory that the oxygen content of the gas supply be determined before a dive. Oxygen analysis is the most common, but not the only type of analytical measurement that is performed in mixed-gas diving. In deep diving systems, scrubbing equipment performance must be monitored by carbon dioxide analysis of the atmosphere. Long-term maintenance of personnel under hyperbaric conditions often necessitates the use of a range of analytical procedures. Analyses are required to determine the presence and concentration of minor quantities of potentially toxic impurities resulting from the off-gassing of materials, metabolic processes, and other sources.

16-3.1 Instrument Selection. Selecting an instrument for analyzing hyperbaric atmospheric constituents shall be determined on an individual command basis. Two important characteristics are accuracy and response time. Accuracy within the range of expected concentration must be adequate to determine the true value of the constituent being studied. This characteristic is of particular importance when a sample must be taken at elevated pressure and expanded to permit analysis. The instrument's response time to changes in concentration is important when measuring constituents that may rapidly change and result in quick development of toxic conditions.

Response times of up to 10 seconds are adequate for monitoring gas concentrations such as oxygen and carbon dioxide in a diving apparatus. When monitoring hyperbaric chamber atmospheres, response times of up to 30 seconds are acceptable. The instruments used should accurately measure concentrations to within 1/10 of the maximum allowable concentration. Thus, to analyze for carbon dioxide with a maximum permissible concentration of 5,000 ppm (SEV), an instrument with an accuracy of at least 500 ppm (SEV) must be used.

In addition to accuracy and response time, portability is a factor in choosing the correct instrument. While large, permanently-mounted instruments are acceptable for installation on fixed-chamber facilities, small hand-carried instruments are better suited for emergency use inside a chamber or at remote dive sites.

16-3.2 Techniques for Analyzing Constituents of a Gas. The constituents of a gas may be analyzed both qualitatively (type determination) and quantitatively (type and amount) using many different techniques and instruments. Guidance regarding instrument selection can be obtained from NAVSEA, NEDU, or from instrument manufacturer technical representatives. Although each technique is not discussed, the major types are listed below as a reference for those who desire to study them in detail.

- Mass spectrometry
- Colorimetric detection
- Ultraviolet spectrophotometry
- Infrared spectrophotometry
- Gas chromatography
- Electrolysis
- Paramagnetism

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