Chapter 2: "Medical Gas and Vacuum Systems"

**GENERAL**

Health care is in a constant state of change, which forces the plumbing engineer to keep up with new technology to provide innovative approaches to the design of medical-gas systems. In designing medical-gas and vacuum systems, the goal is to provide a safe and sufficient flow at required pressures to the medical-gas outlet or inlet terminals served. System design and layout should allow convenient access by the medical staff to outlet/inlet terminals, valves, and equipment during patient care or emergencies.

This section focuses on design parameters and current standards required for the design of nonflammable medical-gas and vacuum systems used in therapeutic and anesthetic care. The plumbing engineer must determine the needs of the health-care staff. Try to work closely with the medical staff to seek answers to the following fundamental design questions at the start of a project:

1. How many outlet/inlets are requested by staff?
2. How many outlet/inlets are required?
3. Based on current conditions, how often is the outlet/inlet used?
4. Based on current conditions, what is the average duration of use for each outlet/inlet?
5. What is the proper usage (diversity) factor to be used?

**MEDICAL-GAS SYSTEM DESIGN CHECKLIST**

As any hospital facility must be specially designed to meet the applicable local code requirements and the health-care needs of the community it serves, the medical-gas and vacuum piping systems must also be designed to meet the specific requirements of each hospital.

Following are the essential steps to a well-designed and functional medical-gas piped system, which are recommended to the plumbing engineer:

1. Analyze each specific area of the health-care facility to determine the following items:
   A. Which piped medical-gas systems are required?
   B. How many of each different type of medical-gas outlet/inlet terminal are required?
   C. Where should the outlet/inlet terminals be located for maximum efficiency and convenience?
   D. Which type and style of outlet/inlet terminal best meet the needs of the medical staff?
2. Anticipate any building expansion and plan in which direction the expansion will take place (vertically or horizontally). Determine how the medical-gas system should be sized and valved in order to accommodate the future expansion.
3. Determine locations for the various medical-gas supply sources.
   A. Bulk oxygen (O₂).
   B. High-pressure cylinder manifolds (O₂, N₂O or N₂).
   C. Vacuum pumps (VAC).
   D. Medical-air compressors (MA).
4. Prepare the schematic piping layout locating the following:
   A. Zone valves.
   B. Isolation valves.
   C. Master alarms.
   D. Area alarms.
5. Calculate the anticipated peak demands for each medical-gas system. Appropriately size each particular section so as to avoid exceeding the maximum pressure drops allowed.
6. Size and select the various medical-gas and vacuum supply equipment that will handle the peak demands for each system, including future expansions. If this project is an addition to an existing facility, determine the following:
   A. What medical gases are currently provided and what are the locations and number of the stations?
   B. Can the current gas supplier (or the hospital’s purchasing department) furnish the consumption records?
   C. Are the capacities of the existing medical-gas supply systems adequate to handle the additional demand?
   D. Are any existing systems valved that could be used for an extension? Are the existing pipe sizes adequate to handle the anticipated additional loads?
   E. What type of equipment is in use and who is the manufacturer? Is this equipment state-of-the-art?
   F. Is it feasible to manifold the new and existing equipment?
   G. What is the physical condition of the existing equipment?
   H. Is there adequate space available for the new medical-gas supply systems and related equipment at the existing location?
   I. Is existing equipment scheduled to be replaced? (A maintenance history of the existing equipment may help in this determination.)

**NUMBER OF STATIONS**

The first step is to locate and count the outlet/inlets, often called “stations,” for each respective medical-gas system. This is usually done by consulting a program prepared by the facility planner or architect. This program is a list of all the rooms and areas in the facility and the services that are required in each. If a program has not been prepared, the floor plans for the proposed facility shall be used.

There is no code that specifically mandates the exact number of stations that must be provided in various areas or rooms for all health-care facilities. In fact, there is no clear consensus of opinion among medical authorities or design professionals as to how many stations are actually required in the facility areas. Guidelines are
published by the American Institute of Architects (AIA), National Fire Protection Association (NFPA), and ASPE that recommend the minimum number of stations for various services in specific areas.

The most often-used recommendations in determining the number of stations for hospitals are those necessary to be accredited by the Joint Commission for the Accreditation of Hospitals Organization (JCAHO). Accreditation is required for Medicare and Medicaid reimbursement. The JCAHO publishes a manual that refers to the AIA guidelines for the minimum number of stations for oxygen, medical air, and vacuum that must be installed in order to obtain accreditation. If this is a factor for the facility, these requirements are mandatory. Other jurisdictions, such as state or local authorities, may require plans to be approved by local health or building officials. These approvals may require adhering to the state or local requirements and/or NFPA 99, Health-Care Facilities.

If accreditation or the approval of authorities is not a factor, the number and area locations of stations are not mandated. The actual count then will depend upon requirements determined by each individual facility or another member of the design team using both past experience and anticipated future use, often using the guideline recommendations as a starting point.

MEDICAL-GAS FLOW RATES

Each station must provide a minimum flow rate for the proper functioning of connected equipment under design and emergency conditions. The flow rates and diversity factors vary for individual stations in each system depending on the total number of outlets and the type of care provided.

The flow rate from the total number of outlets, without regard for any diversity, is called the “total connected load.” If the total connected load were used for sizing purposes, the result would be a vastly oversized system, since not all of the stations in the facility will be used at the same time. A diversity, or simultaneous-use factor, is used to allow for the fact that not all of the stations will be used at once. It is used to reduce the system flow rate in conjunction with the total connected load for sizing mains and branch piping to all parts of the distribution system. This factor varies for different areas throughout any facility.

The estimated flow rate and diversity factors for various systems, area stations, and pieces of equipment are found in Table 1.

Total demand for medical-gas systems varies as a function of time of day, month, patient-care requirements, and facility type. The number of stations needed for patient care is subjective and cannot be qualified based on physical measurements. Knowing the types of patient care and/or authority requirements will allow placement of stations in usage groups. These groups can establish demand and simultaneous-use factors (diversities), which are used in the calculation for sizing a particular system. All medical-gas piping systems must be clearly identified using an approved color-coding system similar to that shown in Table 2.

### Table 1: Outlet Rating Chart for Medical-Vacuum Piping Systems

<table>
<thead>
<tr>
<th>Location of Medical-Surgical Vacuum Outlets</th>
<th>Free-Air Allowance, cfm (L/min) at 1 atmosphere</th>
<th>Zone Allowances — Corridors, Risers, Main Supply Line, Valves</th>
<th>Air to Be Transferred, cfm (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating rooms:</td>
<td>Per Room</td>
<td>Simultaneous Usage Factor (%)</td>
<td>Air to Be Transferred, cfm (L/min)</td>
</tr>
<tr>
<td>Major“A” (Radical, open heart; organ transplant; radical thoracic)</td>
<td>3.5 (100)</td>
<td>100</td>
<td>3.5 (100)</td>
</tr>
<tr>
<td>Major “B” (All other major ORs)</td>
<td>2.0 (60)</td>
<td>100</td>
<td>2.0 (60)</td>
</tr>
<tr>
<td>Minor</td>
<td>1.0 (30)</td>
<td>100</td>
<td>1.0 (30)</td>
</tr>
<tr>
<td>Delivery rooms</td>
<td>1.0 (30)</td>
<td>100</td>
<td>1.0 (30)</td>
</tr>
<tr>
<td>Recovery room (post anesthesia) and intensive-care units (a minimum of 2 outlets per bed in each such department):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st outlet at each bed</td>
<td>3 (85)</td>
<td>50</td>
<td>1.5 (40)</td>
</tr>
<tr>
<td>2nd outlet at each bed</td>
<td>1.0 (30)</td>
<td>50</td>
<td>0.5 (15)</td>
</tr>
<tr>
<td>3rd outlet at each bed</td>
<td>1.0 (30)</td>
<td>10</td>
<td>0.1 (3)</td>
</tr>
<tr>
<td>All others at each bed</td>
<td>1.0 (30)</td>
<td>10</td>
<td>0.1 (3)</td>
</tr>
<tr>
<td>Emergency rooms</td>
<td>1.0 (30)</td>
<td>100</td>
<td>1.0 (30)</td>
</tr>
<tr>
<td>Patient rooms:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgical</td>
<td>1.0 (30)</td>
<td>50</td>
<td>0.5 (15)</td>
</tr>
<tr>
<td>Medical</td>
<td>1.0 (30)</td>
<td>10</td>
<td>0.1 (3)</td>
</tr>
<tr>
<td>Nurseries</td>
<td>1.0 (30)</td>
<td>10</td>
<td>0.1 (3)</td>
</tr>
<tr>
<td>Treatment &amp; examining rooms</td>
<td>0.5 (15)</td>
<td>10</td>
<td>0.05 (1)</td>
</tr>
<tr>
<td>Autopsy</td>
<td>2.0 (60)</td>
<td>20</td>
<td>0.04 (1)</td>
</tr>
<tr>
<td>Inhalation therapy, central supply &amp; instructional areas</td>
<td>1.0 (30)</td>
<td>10</td>
<td>0.1 (3)</td>
</tr>
</tbody>
</table>

*Free air at 1 atmosphere.

### Table 2: Color Coding for Piped Medical Gases

<table>
<thead>
<tr>
<th>Gas Intended for Medical Use</th>
<th>United States Color</th>
<th>Canada Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>Green</td>
<td>Green on white(^1)</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>Gray</td>
<td>Black on gray</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>Blue</td>
<td>Silver on blue</td>
</tr>
<tr>
<td>Cyclopropane</td>
<td>Orange</td>
<td>Silver on orange</td>
</tr>
<tr>
<td>Helium</td>
<td>Brown</td>
<td>Silver on brown</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Black</td>
<td>Silver on black</td>
</tr>
<tr>
<td>Air</td>
<td>Yellow(^2)</td>
<td>White on black and white</td>
</tr>
<tr>
<td>Vacuum</td>
<td>White</td>
<td>Silver on yellow(^3)</td>
</tr>
<tr>
<td>Gas mixtures (other than mixtures of oxygen and nitrogen)</td>
<td>Color marking of mixtures shall be a combination of color corresponding to each component gas.</td>
<td></td>
</tr>
<tr>
<td>Gas mixtures of oxygen and nitrogen 19.5 to 23.5% oxygen</td>
<td>Yellow(^4)</td>
<td>Black and white</td>
</tr>
<tr>
<td>All other oxygen concentrations</td>
<td>Black and green</td>
<td>Pink</td>
</tr>
</tbody>
</table>

Source: Compressed Gas Association, Inc.

\(^1\) Historically, white has been used in the United States and yellow has been used in Canada to identify vacuum systems. Therefore, it is recommended that white not be used in the United States and yellow not be used in Canada as a marking to identify containers for use with any medical gas. Other countries may have differing specific requirements.

MEDICAL-GAS SYSTEM DISPENSING EQUIPMENT

**Medical-gas outlet/inlet terminals** Most manufacturers of medical-gas system equipment offer various types of medical-gas outlets. These medical-gas outlets are available in various gas orders (e.g., O\(_2\), N\(_2\), O\(_2\)/Air), center-line spacing, and for exposed and concealed mountings. Outlet types and configurations must meet the requirements of the local jurisdictional authority and NFPA 99. All outlets must be properly identified and confirmed. Care should also be taken to accurately coordinate the various pieces of medical-gas dispensing equipment with the architect and medical staff involved in the given project. If the project is a renovation, the outlet types should match existing equipment. With prefabricated patient headwall units, the medical-gas outlets are generally furnished by the equipment manufacturer, and it is very important that coordination be maintained by the engineer so that unnecessary
sary duplication of work is avoided. Also, with regard to the over-the-bed medical-gas service consoles, these consoles are often specified in the electrical or equipment section of the specification and medical-gas service outlets are specified, furnished, and installed under the mechanical contract.

Gas-outlet sequence, center-line spacing, and multiple-gang-service outlets are some of the considerations to be taken into account when requesting information from the various equipment manufacturers. It is more practical, in terms of both the cost of the equipment and the installation, to specify and select the manufacturer’s standard outlet(s). Details and specifications regarding the individual standard outlets are usually available from all manufacturers upon request.

The existing outlets are compatible with the adapters found on the hospital’s anesthesia machines, flow meters, vacuum regulators, etc. Care should be taken to make sure all future expansions in the same facility have compatible equipment.

**Patient head-wall systems** A recent and growing trend in hospital construction is the requirement for patient head-wall systems, which incorporate many services for the patient’s care. These units may include the following:

1. Medical-gas outlets.
2. Electrical-service outlets (including emergency power).
3. Direct and indirect lighting.
4. Nurse-call system.
5. Isolation transformers.
7. Patient-monitoring receptacles.
8. Vacuum slide and IV brackets.
10. Electrical switches.

Bed locator units are also available, which serve to provide power for the more advanced patient beds, telephone, night lights, and standard power. These units also function to protect the walls from damage as beds are moved and adjusted.

Head walls currently vary in shape, size, type, and cost from a simple over-the-patient-bed standard configuration to elaborate total-wall units. Most manufacturers of medical-gas equipment offer medical-gas outlets for all types of patient consoles available in today’s market. When specifying head-walls outlets, the plumbing engineer should consider the following:

1. Is the service outlet selected compatible with the existing outlet component?
2. Does the patient head-wall manufacturer include the type of medical-gas outlets required as part of the product?

**Special types of ceiling-mounted, medical-gas out-

### Table 3  Types of Dispensing Equipment for Specific Areas

<table>
<thead>
<tr>
<th>Hospital Areas</th>
<th>Medical Gas Outlet Dispensing Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wall-Mounted Outlets</td>
</tr>
<tr>
<td>Autopsy rooms</td>
<td>●</td>
</tr>
<tr>
<td>Delivery rooms</td>
<td>●</td>
</tr>
<tr>
<td>Emergency examination and treatment rooms</td>
<td>●</td>
</tr>
<tr>
<td>Emergency operating rooms</td>
<td>●</td>
</tr>
<tr>
<td>Induction rooms</td>
<td>●</td>
</tr>
<tr>
<td>Labor rooms</td>
<td>●</td>
</tr>
<tr>
<td>Major surgery rooms</td>
<td>●</td>
</tr>
<tr>
<td>Minor surgery, cystoscopy</td>
<td>●</td>
</tr>
<tr>
<td>Neonatal intensive care units</td>
<td>●</td>
</tr>
<tr>
<td>Normal nursery rooms</td>
<td>●</td>
</tr>
<tr>
<td>Nursery workrooms</td>
<td>●</td>
</tr>
<tr>
<td>O.B. recovery rooms</td>
<td>●</td>
</tr>
<tr>
<td>Patient rooms</td>
<td>●</td>
</tr>
<tr>
<td>Pediatric and youth intensive care unit</td>
<td>●</td>
</tr>
<tr>
<td>Post-operative recovery rooms</td>
<td>●</td>
</tr>
<tr>
<td>Premature and pediatric nursery rooms</td>
<td>●</td>
</tr>
<tr>
<td>Pre-op holding rooms</td>
<td>●</td>
</tr>
<tr>
<td>Radiology rooms</td>
<td>●</td>
</tr>
<tr>
<td>Respiratory care unit</td>
<td>●</td>
</tr>
<tr>
<td>Specialized surgeries (cardiac and neuro)</td>
<td>●</td>
</tr>
</tbody>
</table>
areas. The ceiling gas-service outlets are generally located at both the head and the foot of the operating table in order to provide alternate positioning of the operating table.

2. Surgical ceiling columns Surgical ceiling columns are usually available in two designs: rigid (a predetermined length from the ceiling height above the floor) and retractable. Both surgical ceiling columns provide medical-gas services within an enclosure that projects down from the ceiling. The ceiling columns are usually located at opposite ends of the operating table in order to provide convenient access to the medical-gas outlets by the anesthesiologist. In addition to the medical-gas outlets, these ceiling columns can be equipped with electrical outlets, grounding receptacles, physiological monitor receptacles, and hooks for hanging intravenous-solution bottles.

Most manufacturers offering surgical ceiling columns allow for many variations in room arrangements of medical-gas services and related accessories, depending upon the specific customer’s needs and the engineer’s specifications. When specifying this type of equipment, it is necessary to specify carefully all medical-gas service requirements and their desired arrangement(s). Also, the engineer must coordinate all other required services with the electrical engineer and medical staff.

3. Surgical gas tracks Surgical gas tracks are forms of ceiling outlet and hose-drop arrangements that allow the movement of the hose drops from one end of the operating table to the other on sliding tracks mounted on the ceiling. These products are currently available from various manufacturers and all provide the same basic services. The proper selection and specification of specific types are based on individual customer preference. Many variations in products and particular product applications are available in critical (intensive) care areas. Consultation with appropriate manufacturers for recommendations is always advisable.

4. Articulating ceiling-service center Articulated ceiling-service centers are moved by pneumatic drive systems and are designed for the convenient dispensing of medical-gas and electrical services in operating rooms. The medical-gas and electrical systems are complete for single-point connection to each outlet at the mounting support platform.

High-pressure nitrogen (N\textsubscript{2}) dispensing equipment Special consideration must be given by the plumbing engineer to the placement of the nitrogen outlets. The primary use of nitrogen gas in hospitals is for driving turbo-surgical instruments. Variations of these turbo-surgical instruments, in both their manufacture and their intended use, will require that several different nitrogen-gas pressure levels be available. For this reason, it is necessary that the engineer provide an adjustable pressure-regulating device near the nitrogen gas outlet. A nitrogen control panel is usually located on the wall (in the surgery room) opposite the operating area sterile field. The installation should allow for the access and adjustment of pressure settings by a surgical nurse.

Piping from the nitrogen control panel to a surgical ceiling outlet will provide a convenient source of nitrogen for surgical tools. This will prevent hoses from being located on the floor or between the wall outlet and the operating table. Excess hose can be obstructive to the surgical team.

MEDICAL-GAS STORAGE

After deciding the medical-gas services to be provided at the facility, the engineer should determine the storage capacity and the pipe sizing required and possible locations for the source. Local codes and references as well as the administrative authority having jurisdiction should be consulted for each medical-gas system.

Because of the unique characteristics of each medical-gas source, the gases are described separately in this section. Also, an explanation of the techniques currently employed to exhaust anesthetic gases is provided.

Oxygen (O\textsubscript{2}) Several factors must be known when estimating the monthly consumption of oxygen in new or existing healthcare facilities:

1. Type of medical care provided.
2. Number of oxygen outlets or
3. Number of patient beds.
4. Future expansion of facility.
5. In existing facilities, approximate consumption.

Two methods can be used by the plumbing engineer to estimate the consumption of oxygen. The more accurate method is to obtain a detailed consumption record from the health-care facility or obtain monthly oxygen shipment invoices from the supplier. If inventory records are not available from the health-care facility or the supplier, use consumption records from a comparable sized facility, with good judgment.

The second method is to apply the following rule of thumb to estimate the monthly supply of oxygen. This estimating method should be used with good judgment. Always coordinate estimated demand with the oxygen supplier during the design process.

1. In non-acute-care areas, allow 500 ft\textsuperscript{3} (14 m\textsuperscript{3}) per bed per month for supply and reserve oxygen storage.
2. In acute-care areas, allow 1000 ft\textsuperscript{3} (28 m\textsuperscript{3}) per bed per month for supply and reserve oxygen storage.

Oxygen supply sources are divided into two categories: (1) bulk-oxygen systems and (2) cylinder-manifold-supply systems. Bulk-oxygen systems should be considered for health-care facilities with an estimated monthly demand above 35,000 ft\textsuperscript{3} (991 m\textsuperscript{3}) or equal to 70 oxygen outlets. Manifold systems are used in small general hospitals or clinics.

**Bulk-oxygen systems** When selecting and placing bulk-oxygen systems, there are several factors to be considered: Oxygen transport truck size, truck access to bulk-storage tanks, and NFPA 50, Standard for Bulk Oxygen Systems at Consumer Sites. Bulk-oxygen equipment, construction, installation, and location must comply with NFPA 50 recommendations. If liquid oxygen is spilled or leaked, an extreme fire or explosive hazard could occur. NFPA has design standards to minimize fire exposure to and from surrounding structures.

Bulk-storage systems consist of cryogenic tanks that store liquid oxygen at low pressures (225 psi [1551.3 kPa] or less). Cryogenic tanks are ASME unfired, double-walled, vacuum-insulated, pressure vessels. Liquid oxygen has a boiling point (nbp) of -297.3°F (-182.9°C) and a liquid density of 71.27 lb/ft\textsuperscript{3} (1141.8 kg/cm\textsuperscript{3}). When vaporized into gas, it produces 900 times its liquid volume. Furthermore, since the tank is changed less often, process stability is maximized and the introduction of atmospheric impurities is reduced. Tank systems are furnished with an integral pressure-relief valve vented to the atmosphere should the liquid oxygen convert to a gas.
Most bulk-oxygen storage systems are furnished with vaporizers. Vaporizers are banks of finned-tube heat exchangers that convert the liquid to its gaseous state. The vaporizers come in several styles—including atmospheric, powered (forced-air, steam, and electric), waste-heat, and hybrid—and sizes. The selection of vaporizers should be based on demand, intermittent or continuous usage, energy costs, and temperature zones. Poorly ventilated sites or undersized heat exchangers can cause ice to form on vaporizers during the conversion process. Excessive ice formations can clog and damage the vaporizer. Also, ice could allow extremely cold gas or the cryogenic liquid to enter the piped system; damage the valves, alarms, and medical components; and even injure patients. Figure 1 illustrates a typical bulk-oxygen system schematic.

Automatic controls furnished with the tanks regulate the flow of liquid through the vaporizers. When there is a demand for oxygen, the supply system draws liquid from the bottom of the cryogenic storage tank through the vaporizers. The gas moves through a final line regulator. Thus, a constant supply of oxygen at a regulated pressure is provided.

In case of mechanical difficulty or the depletion of the liquid-oxygen supply, the reserve supply will begin to feed into the distribution system automatically.

An alarm signal should alert appropriate hospital personnel when the liquid in the oxygen storage tank reaches a predetermined level. The alarm signals should indicate low liquid levels, reserve in use, and reserve low.

Cylinder-manifold supply systems Compressed-oxygen systems are comprised of cylinder manifolds that allow a primary supply source of oxygen cylinders to be in use and an equal number of oxygen cylinders to be connected as a reserve supply. The controls of the cylinder manifold will automatically shift the flow of the oxygen gas from the service side to the reserve side when the service side is depleted.

Manifold systems can be located indoors or outdoors. When manifolds are located indoors, the engineer should observe the following:

- **Location** Preferably, the manifold should be in a dedicated room on an outside wall near a loading dock and have adequate ventilation and service convenience.

- **Adjacent areas** There should be no doors, vents, or other direct communications between the anesthetizing location or the storage location and any combustible agents. If locating near or adjacent to an elevated temperature area is unavoidable, the engineer should specify sufficient insulation to prevent cylinder overheating.

- **Fire rating** The fire-resistance rating of the room should be at least 1 h.

- **Ventilation** Outside ventilation is required.

- **Security** The room (or area) must be provided with a door or a gate that can be locked and labeled.

Oxygen manifolds are sized taking into consideration the following:

1. The size of the cylinders, 244 ft³ (6909 L) H-cylinder (see Table 4 for a sizing chart).
2. The hospital’s usage of oxygen, in ft³ (L) per month.
Nitrous oxide \((\text{N}_2\text{O})\)  The common source of nitrous oxide is a cylinder-manifold system. High-pressure manifold systems consist of two banks of cylinders, primary and reserve. (See discussion under “Oxygen,” above.)

System demands for nitrous oxide can be more difficult to determine than they are for other medical gases. The number of surgeries scheduled, the types and lengths of surgery, and the administering techniques used by the anesthesiologists cause extreme variations in the amount of nitrous oxide used. Because of this variation, considerations must be given to the size and selection of the nitrous-oxide manifold system.

Avoid locating the nitrous-oxide manifold system outdoors in areas with extremely cold climates. Nitrous oxide is supplied liquefied at its vapor pressure of 745 psi (5136.6 kPa) at 70°F (21.1°C). At extremely cold temperatures, the cylinder pressure will drop dramatically, reducing the cylinder pressure to a point where it is impossible to maintain an adequate line pressure. This is due to a lack of heat for vaporization.

For nitrous-oxide manifolds located indoors, the same precautions previously listed for oxygen systems must be observed.

The following should be considered when selecting and sizing nitrous-oxide manifolds and determining the number of cylinders required:

1. The size of the cylinders: 489 ft\(^3\) (13.847 L) K-cylinders (see Table 5).
2. The number of anesthetizing locations or operating rooms.
3. Provide \(\frac{1}{2}\) of 1 cylinder per operating room for in-service and reserve supplies.

### Table 4 Selection Chart for Oxygen Manifolds

<table>
<thead>
<tr>
<th>Cu. Ft. (10(^3) L) per month</th>
<th>Total Cylinders</th>
<th>Cylinders per Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,856</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>9,760</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>13,664</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td>17,568</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>21,472</td>
<td>22</td>
<td>11</td>
</tr>
<tr>
<td>25,376</td>
<td>26</td>
<td>13</td>
</tr>
<tr>
<td>29,280</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>33,154</td>
<td>34</td>
<td>17</td>
</tr>
</tbody>
</table>

Note: Based on use of 244 ft\(^3\) (6909.35 L) H-cylinders.

### Table 5 Sizing Chart for Nitrous Oxide Cylinder Manifolds

<table>
<thead>
<tr>
<th>Number of Operating Rooms</th>
<th>Indoor</th>
<th>Outdoor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Cylinders</td>
<td>Cylinders per Side</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>4</td>
</tr>
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<td>12</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>8</td>
</tr>
</tbody>
</table>

Note: Based on use of 489 ft\(^3\) (13.85 \times 103 L) K-cylinders.

### Medical compressed air

Medical compressed air may be supplied by two types of system: (1) a high-pressure cylinder-manifold system; and (2) a medical air-compressor system.

The manifold systems for compressed air are similar in configuration to those for oxygen and nitrous oxide (see discussion under “Oxygen,” above). Air supplied from cylinders or that has been reconstituted from oxygen U.S.P. and nitrogen N.F. must comply, as a minimum, with Grade D in ANSI ZE86.1, *Commodity Specification for Air*.

Medical compressed air can be produced on site from atmospheric air using air compressors designed for medical applications. There are three major types of air compressor in the marketplace today: the centrifugal, reciprocating, and rotary screw. The reciprocating and rotary screw are “positive-displacement” type units, while the centrifugal compressor is a “dynamic” type compressor. The medical air compressor shall be designed to prevent the introduction of contaminants or liquid into the pipeline by one of two methods: Type 1 air compressors eliminate oil anywhere in the compressor. Type 2 air compressors separate the oil-containing section from the compression chamber. Examples of a type 1 compressor are the liquid ring, rotary screw, and permanently sealed bearing compressor. Type 2 compressors have extended heads.

A positive-displacement compressor is normally rated in actual cubic feet per minute (acfm). This is the amount of air taken from atmospheric conditions that the unit will deliver at its discharge. Within a broad range, changes in inlet air temperature, pressure, and humidity do not change the acfm rating of either the reciprocating or the rotary screw compressor. The centrifugal compressor’s capacity, however, is affected slightly by the inlet air conditions due to the nature of the compression process. For example, as the air temperature decreases, the capacity of the dynamic compressor will increase. The capacity of a centrifugal compressor is normally defined in inlet cubic feet per minute (icfm). In an effort to obtain an “apples to apples” comparison of various compressors, many manufacturers specify their capacity requirements in standard cubic feet per minute (scfm). This sometimes causes much confusion because many people do not fully understand how to convert from acfm or icfm to scfm. The design engineer specifying scfm must define a typical inlet air condition at the building site and their set of “standard” conditions (normally 14.7 psia [101.4 kPa], 60°F [15.6°C], and 0% relative humidity). Typically, the warmest normal condition is specified because as the temperature goes up scfm will go down.

To convert from acfm to scfm, the following equation is used.

**Equation 1**

\[
\text{scfm} = \text{acfm} \times \frac{P_i - (P_{pi} \times \%RH)}{P_{std} - (P_{p std} \times \%RH_{std})} \times \frac{T_{std}}{T_i}
\]

where

- \(P_i\) = Initial pressure
- \(P_{pi}\) = Partial initial pressure of water vapor in 100% humid air at the temperature in question
- RH = Relative humidity
- \(P_{std}\) = Pressure under standard conditions
- \(P_{p std}\) = Partial standard pressure of water vapor in 100% humid air at the temperature in question
- \(RH_{std}\) = Relative humidity at standard conditions
- \(T_{std}\) = Temperature at standard conditions, °F (°C)
- \(T_i\) = Inlet temperature, °F (°C)
Equation 1a
This equation is derived from the Perfect Gas law, which is:
\[
\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}
\]
or:
\[
V_2 = V_1 \times \frac{P_1 / T_1}{P_2 / T_2}
\]
where
- \(P_1\) = Initial pressure
- \(V_1\) = Initial volume
- \(T_1\) = Initial temperature
- \(P_2\) = Final pressure
- \(V_2\) = Final volume
- \(T_2\) = Final temperature

For a reciprocating or rotary-screw compressor, the conversion from acfm to scfm is simple. The inlet air conditions and standard conditions are inserted into the above formula and multiplied by the acfm capacity of the unit. It makes no difference what the design conditions are for that compressor, as these do not figure into the formula. In the case of a dynamic compressor, the icfm air flow at the given inlet conditions is inserted in place of the acfm in the formula. Another design issue that the engineer should be aware of is how altitude affects the output of the compressor. At altitudes above sea level, all medical-air systems have reduced flow. In these cases, the required sizing will need to be adjusted to compensate. To do this, multiply the scfm requirements by the correction factor in Table 6.

### Table 6 Altitude Correction Factors for Medical-Air Systems

<table>
<thead>
<tr>
<th>Altitude, ft (m)</th>
<th>Normal Barometric Pressure, in. Hg (mm Hg)</th>
<th>Correction Factor for SCFM (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea level</td>
<td>29.92 (759.97)</td>
<td>1.0 (28.31)</td>
</tr>
<tr>
<td>1,000 (304.8)</td>
<td>28.86 (733.04)</td>
<td>1.01 (28.6)</td>
</tr>
<tr>
<td>2,000 (609.6)</td>
<td>27.82 (706.63)</td>
<td>1.03 (29.16)</td>
</tr>
<tr>
<td>3,000 (914.4)</td>
<td>26.82 (681.23)</td>
<td>1.05 (29.73)</td>
</tr>
<tr>
<td>4,000 (1219.2)</td>
<td>25.84 (656.33)</td>
<td>1.06 (30.01)</td>
</tr>
<tr>
<td>5,000 (1524)</td>
<td>24.90 (632.46)</td>
<td>1.08 (30.58)</td>
</tr>
<tr>
<td>6,000 (1828.8)</td>
<td>23.98 (609.09)</td>
<td>1.10 (31.14)</td>
</tr>
<tr>
<td>7,000 (2133.6)</td>
<td>23.09 (586.48)</td>
<td>1.12 (31.71)</td>
</tr>
<tr>
<td>8,000 (2438.4)</td>
<td>22.23 (564.64)</td>
<td>1.15 (32.56)</td>
</tr>
<tr>
<td>9,000 (2743.2)</td>
<td>21.39 (543.3)</td>
<td>1.17 (33.13)</td>
</tr>
<tr>
<td>10,000 (3048)</td>
<td>20.58 (522.7)</td>
<td>1.19 (33.69)</td>
</tr>
</tbody>
</table>

In other words, to correctly size the medical-air system, you would apply the correction factor listed in the chart above to the peak-calculated load (scfm) at sea level.

**Example 2**
A facility is located at 5000 ft (1524 m) above sea level and the system demand is 29.4 SCFM. Take the 29.4 scfm and multiply it by 1.08 (correction factor from Table 5) to get the adjusted scfm requirement of 31.8 scfm at 5000 ft above sea level. Therefore, a medical-air system of greater capacity is needed at higher altitudes.

Another handy formula for compressed-air systems is the following: to convert scfm to L/min multiply by 28.31685.

Each compressor must be capable of maintaining 100% of the medical-air peak demand regardless of the standby compressor’s operating status. The basic compressor package consists of filter intakes, duplex compressors, after-coolers, receiving tanks, air dryers, in-line filters, regulators, dew-point monitors, and valves. The compressor components are connected by piping that allows equipment isolation, provides pressure relief, and removes condensate from receivers. Medical-air compressors must draw outside air from above the roof level, remote from any doors, windows, and exhaust or vent openings. Where the outside atmospheric air is polluted, special filters can be attached to the compressor’s intake to remove carbon monoxide and other contaminants. Refer to NFPA 99 for proper location of medical-air intakes. Medical compressed air must comply with NFPA 99 and/or Canadian Standards Association’s (CSA’s) definition of air-quality standards.

Where more than two units are provided for the facility, any two units must be capable of supplying the peak calculated demands. Provide automatic alternators (duty-cycling controls) to ensure even wear in normal usage. Alternator controls incorporate a positive means of automatically activating the additional unit (or units) should the in-service pump fail to maintain the minimum required pressure.

Medical compressed air produced by compressors may be defined as “outside atmosphere to which no contaminants (in the form of particulate matter, odors, oil vapors, or other gases) have been added by the compressor system.” Not every compressor is suitable for use as a source for medical compressed air in healthcare facilities. Only those compressor units specifically designed and manufactured for medical purposes should be considered as a reliable source of oil-free, moisture-free, and low-temperature compressed air. Acceptable compressor types include oil-free, oilless, and liquid-ring compressors. Separation of the oil-containing section from the compression chamber by at least two seals is required by the compressor manufacturers.

Air compressed for medical-breathing purposes are to be used for this purpose only and should not be used for other applications or cross-connected with other compressed air systems.

### Table 7 Minimum Pipe Sizes for Medical Air-Compressor Intake Risers

<table>
<thead>
<tr>
<th>Pipe size, in. (mm)</th>
<th>Flow rate, cfm (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 (63.5)</td>
<td>50 (1416)</td>
</tr>
<tr>
<td>3 (76.2)</td>
<td>70 (1985)</td>
</tr>
<tr>
<td>4 (101.6)</td>
<td>210 (5950)</td>
</tr>
<tr>
<td>5 (127.0)</td>
<td>400 (11330)</td>
</tr>
</tbody>
</table>

Table 7 provides the minimum pipe sizes for medical air-compressor intake risers. Consult with the compressor manufacturer on intake recommendations and allowable friction loss for the intake riser before finalizing the pipe size equipment selection.

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1. When liquid oxygen is vaporized into a gas, it produces ________ times its liquid volume.
   a. 0
   b. 450
   c. 900
   d. 1,350

2. Nitrous oxide (N₂O) is typically used by whom in the surgery room?
   a. the attending physician
   b. the attending physician’s assistant
   c. the surgical nurse
   d. the anesthesiologist

3. The medical-gas and vacuum piping systems must be designed to ________.
   a. meet the specific requirements of each hospital
   b. anticipate any building expansion
   c. not cross connect to any existing system
   d. all of the above

4. The primary use of nitrogen gas in hospitals is ________.
   a. driving turbo-surgical instruments
   b. pressurizing piping systems
   c. in the laboratory Bunsen burners
   d. none of the above

5. Medical-gas flow rates ________.
   a. must include diversification
   b. must provide for the total connected load
   c. must provide the minimum required flow for the proper functioning of connected equipment
   d. must be estimated

6. Providing medical-gas service outlets in the surgery room may be accomplished by locating them in ________.
   a. the ceiling
   b. the surgical ceiling columns
   c. the surgical gas tracks
   d. any of the above noted areas and others not listed

7. In acute-care areas, allow ________ cubic feet per bed per month for supply and reserve oxygen storage.
   a. 250
   b. 500
   c. 750
   d. 1,000

8. The exact number of medical-gas outlets required in the various areas or rooms is mandated by ________.
   a. the various codes that apply to work at the project site
   b. the American Institute of Architects (AIA)
   c. the National Fire Protection Association (NFPA)
   d. none of the above

9. Medical-gas outlet types and configurations must meet the requirements of the local jurisdictional authority and ________.
   a. ANSI 1416
   b. NFPA 99
   c. NFPA 50
   d. ANSI 1763

10. Several factors must be known when estimating the monthly consumption of oxygen, such as ________.
    a. the number of patient beds
    b. the type of medical care provided
    c. the future expansion plans of the facility
    d. all of the above

11. What is the SCFM correction factor for a medical-air system located in a facility at an altitude of 7,000 feet above sea level?
    a. 1.05
    b. 1.08
    c. 1.12
    d. 1.17

12. The goal in designing medical-gas and vacuum systems is ________.
    a. to provide a safe system
    b. to provide a sufficient flow of gas or vacuum
    c. to provide the required pressure
    d. all of the above
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