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# Standard Guide for Cleanliness Levels and Cleaning Methods for Materials and Equipment Used in Oxygen-Enriched Environments<sup>1</sup>

This standard is issued under the fixed designation G93/G93M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This guide covers the selection of methods and apparatus for cleaning materials and equipment intended for service in oxygen-enriched environments. Contamination problems encountered in the use of enriched air, mixtures of oxygen with other gases, or any other oxidizing gas may be solved by the same cleaning procedures applicable to most metallic and nonmetallic materials and equipment. Cleaning examples for some specific materials, components, and equipment, and the cleaning methods for particular applications, are given in the appendices.

1.2 This guide includes levels of cleanliness used for various applications and the methods used to obtain and verify these levels.

1.3 This guide applies to chemical-, solvent-, and aqueous-based processes.

1.4 This guide describes nonmandatory material for choosing the required levels of cleanliness for systems exposed to oxygen or oxygen-enriched atmospheres.

1.5 This guide proposes a practical range of cleanliness levels that will satisfy most system needs, but it does not deal in quantitative detail with the many conditions that might demand greater cleanliness or that might allow greater contamination levels to exist. Furthermore, it does not propose specific ways to measure or monitor these levels from among the available methods.

1.6 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the*

*responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* Federal, state, and local safety and disposal regulations concerning the particular hazardous materials, reagents, operations, and equipment being used should be reviewed by the user. The user is encouraged to obtain the Material Safety Data Sheet (MSDS) from the manufacturer for any material incorporated into a cleaning process. Specific cautions are given in Section 8.

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

2.1 *ASTM Standards:*<sup>2</sup>

D1193 Specification for Reagent Water

D2200 Practice for Use of Pictorial Surface Preparation Standards and Guides for Painting Steel Surfaces

E312 Practice for Description and Selection of Conditions for Photographing Specimens Using Analog (Film) Cameras and Digital Still Cameras (DSC) (Withdrawn 2017)<sup>3</sup>

F312 Test Methods for Microscopical Sizing and Counting Particles from Aerospace Fluids on Membrane Filters

F331 Test Method for Nonvolatile Residue of Solvent Extract from Aerospace Components (Using Flash Evaporator)

G63 Guide for Evaluating Nonmetallic Materials for Oxygen Service

G88 Guide for Designing Systems for Oxygen Service

G122 Test Method for Evaluating the Effectiveness of Cleaning Agents

G127 Guide for the Selection of Cleaning Agents for

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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>3</sup> The last approved version of this historical standard is referenced on [www.astm.org](http://www.astm.org).

### Oxygen-Enriched Systems

**G131 Practice for Cleaning of Materials and Components by Ultrasonic Techniques**

**G136 Practice for Determination of Soluble Residual Contaminants in Materials by Ultrasonic Extraction**

**G144 Test Method for Determination of Residual Contamination of Materials and Components by Total Carbon Analysis Using a High Temperature Combustion Analyzer**

2.2 CGA Documents:<sup>4</sup>

**CGA Pamphlet G-4.1 Cleaning Equipment for Oxygen Service**

**CGA Pamphlet G-4.4 Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems**

2.3 SAE Document:<sup>5</sup>

**ARP 598 The Determination of Particulate Contamination in Liquids by the Particle Count Method**

2.4 ISO Document:<sup>6</sup>

**ISO 14644-1 Cleanrooms and Associated Controlled Environments—Part 1: Classification of Air Cleanliness**

3.1.6 *qualified technical personnel, n*—persons such as engineers and chemists who, by virtue of education, training, or experience, know how to apply physical and chemical principles involved in the reactions between oxidants and other metals.

#### 3.2 Definitions of Terms Specific to This Standard:

3.2.1 *cleanliness, n*—the degree to which an oxygen system is free of contaminant.

3.2.2 *fibers, n*—particulate matter with a length of 100 μm or greater, and a length-to-width ratio of 10 to 1 or greater.

3.2.3 *particulate, n*—a general term used to describe a finely divided solid of organic or inorganic matter.

3.2.3.1 *Discussion*—These solids are usually reported as the amount of contaminant by the population of a specific micrometer size. See methods described in Test Methods **F312** or **ARP 598** for particle size and population determination.

### 4. Summary of Guide

4.1 General methods, apparatus, and reagents for cleaning materials and equipment used in oxygen-enriched environments are described in this guide. Exact procedures are not given because they depend on the contaminant type and material to be cleaned, cleaning agent used, and degree of cleanliness required. Methods may be used individually, or may be combined or repeated to achieve the desired results. Examples of cleaning procedures that have been successfully used for specific materials, components, and equipment in selected applications are described in the appendices. An index of the specific materials, components, equipment, and applications covered in these examples is given in **Table X1.1**.

4.2 For the purpose of this guide, both solid and fluid contaminants have been subclassed into three categories: organics, inorganics, and particulates. A list of common contamination levels is given in **Table 1**.

4.3 Cleanliness specifications that have been used in the past are identified, levels of cleanliness that can be achieved are listed along with factors that suggest potential upper limits for allowable system contamination, and the practical difficulties in adopting and achieving adequately clean systems are reviewed. Cleanliness specifications used by suppliers and manufacturers often differ; it is therefore important to communicate and agree upon which specification is to be used for a given system and to adhere to the most conservative measures.

### 3. Terminology

#### 3.1 Definitions:

3.1.1 *contaminant, n*—unwanted molecular or particulate matter that could adversely affect or degrade the operation, life, or reliability of the systems or components upon which it resides.

3.1.2 *contamination, n*—(1) the amount of unwanted molecular or particulate matter in a system; (2) the process or condition of being contaminated.

3.1.2.1 *Discussion*—Contamination and cleanliness are opposing properties; increasing cleanliness implies decreasing contamination.

3.1.3 *direct oxygen service, n*—service in contact with oxygen-enriched atmosphere during normal operation.

3.1.3.1 *Discussion*—Examples are oxygen compressor piston rings or control valve seats.

3.1.4 *nonmetal, n*—any material other than a metal, non-polymeric alloy, or any composite in which the metallic component is not the most easily ignited component and for which the individual constituents cannot be evaluated independently, including ceramics (such as glass), synthetic polymers (such as most rubbers, thermoplastics, and thermosets), and natural polymers (such as naturally occurring rubber, wood, and cloth).

3.1.4.1 *Discussion*—Nonmetallic is the adjective use of this term.

3.1.5 *oxygen compatibility (also oxidant compatibility), n*—the ability of a substance to coexist with both oxygen and a potential source(s) of ignition at an expected pressure and temperature with a magnitude of risk acceptable to the user.

<sup>4</sup> Available from Compressed Gas Association (CGA), 4221 Walney Rd., 5th Floor, Chantilly, VA 20151-2923, <http://www.cganet.com>.

<sup>5</sup> Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, <http://www.sae.org>.

<sup>6</sup> Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, <http://www.iso.ch>.

**TABLE 1 Oil Film Contamination Level Specifications<sup>A</sup>**

Concentration, mg/m <sup>2</sup> (mg/ft <sup>2</sup> )	Source
0.14 (0.013)	1967 Navy Standard per Presti and DeSimone <b>(1)</b>
10.8 (1)	NASA KSC 123 per Report MTB 306-71 <b>(2)</b>
16.1 (1.5)	Recommended by Presti and DeSimone <b>(1)</b>
43.1 (4)	Air Force 1950s value per LeSuer <b>(3)</b>
75.3 (7)	Recommended by Walde <b>(4)</b>
108 (10 mg/ft <sup>2</sup> or per item)	Union Carbide Guideline <b>(5,6)</b>
50 to 100 (4.6 to 9.3)	Compressed Gas Association Pamphlet G-4.8 <b>(7)</b>
500 (47.5)	Compressed Gas Association Pamphlet G-4.1 <b>(8)</b>

<sup>A</sup> The boldface numbers in parentheses refer to the list of references at the end of this standard.

## 5. Significance and Use

5.1 The purpose of this guide is to furnish qualified technical personnel with pertinent information for the selection of cleaning methods for cleaning materials and equipment to be used in oxygen-enriched environments. This guide furnishes qualified technical personnel with guidance in the specification of oxygen system cleanliness needs. It does not actually specify cleanliness levels.

5.2 Insufficient cleanliness of components used in oxygen systems can result in the ignition of contaminants or components by a variety of mechanisms such as particle, mechanical, or pneumatic impact. These mechanisms are explained in detail in Guide **G88**.

5.3 Adequate contamination control in oxygen systems is imperative to minimize hazards and component failures that can result from contamination. Contamination must also be minimized to ensure an acceptable product purity.

5.4 Removal of contaminants from materials and components depends on system configuration, materials of construction, and type and quantity of contaminant.

5.5 Examples of cleaning procedures contained herein may be followed or specified for those materials, components, and equipment indicated. The general cleaning text can be used to establish cleaning procedures for materials, components, equipment, and applications not addressed in detail. See Guide **G127** for discussion of cleaning agent and procedure selection.

## 6. Interferences

### 6.1 *Disassembly:*

6.1.1 It is imperative that oxygen systems be cleaned as individual components or piece parts, preferably before assembly. Assembled systems must be disassembled for cleaning if construction permits. Flushing an assembled system can deposit and concentrate contaminants in stagnant areas. Nonvolatile cleaning agents may remain in trapped spaces and later react with oxygen. Cleaning solutions may degrade nonmetals in an assembly. Caustic and acid cleaning solutions may cause crevice corrosion in assemblies.

6.1.2 Manufactured products (that is, valves, regulators, and pumps) should be cleaned preferably by the manufacturer before final assembly and test. All tests should be structured to prevent recontamination. The part must then be packaged in oxygen-compatible materials (see **12.1**) and identified to protect it from contamination in transit and storage. The purchaser should approve the cleaning procedure and packaging to assure that they satisfy system requirements. Some purchasers may require the product manufacturer to certify cleanliness level and oxygen compatibility of all component materials.

6.1.3 Manufactured products cleaned by the purchaser must be disassembled for cleaning if construction permits. The purchaser should follow the manufacturer's instructions for disassembly, inspection for damage, reassembly, and testing.

### 6.2 *Cleaners:*

6.2.1 Mechanical cleaning methods such as abrasive blasting, tumbling, grinding, and wire brushing are very aggressive and should be avoided on finished machined ar-

ticles. Such methods can damage sealing surfaces, remove protective coatings, and work-harden metals. Sensitive surfaces must be protected before mechanical cleaning methods are applied.

6.2.2 Chemical cleaners, both acid and caustic, can damage metal parts if not neutralized upon completion of cleaning. Corrosion, embrittlement, or other surface modifications are potentially harmful side effects of chemical cleaning agents. Crevice corrosion can occur and sealing surfaces can be etched enough to destroy the finish necessary to seal the part. See Test Method **G122** and Guide **G127** for methods used to evaluate cleaners for use on various materials used in oxygen service.

6.2.3 Solvent cleaning solutions often damage plastics and elastomers. The manufacturer should be consulted or sample parts should be tested to ensure that the solvent is not harmful to the item being cleaned.

### 6.3 *Lubricants:*

6.3.1 Mechanical components are normally assembled with lubricants on seals, threads, and moving surfaces. The manufacturer should be consulted to determine the kind of lubricant originally used on the article to ensure that the cleaning solutions and methods selected are effective in removing the lubricant and will not damage the component.

6.3.2 Oxygen-compatible lubricants should be selected in accordance with Guide **G63**. The component manufacturer should also be consulted to ensure that the selected lubricant provides adequate lubrication for component performance. Oxygen-compatible lubricants often have markedly different lubricating properties from conventional lubricants.

### 6.4 *Environment and Assembly Requirements:*

6.4.1 Equipment intended for oxygen service must be handled carefully during all phases of a cleaning procedure. The environment should be clean and dust-free. Nearby grinding, welding, and sanding should be prohibited. Parts should not be allowed to stand in the open unprotected after they have been cleaned. Care should be taken to avoid contamination by oil deposits from rotating machinery or oil aerosols in the air. Do not touch part surfaces that will be in direct oxygen service except with clean gloves or handling devices.

6.4.2 In some cases, laminar-flow clean rooms may be necessary in which the entire room is purged with filtered air. In horizontal flow clean rooms, parts are cleaned and verified in a sequence in which successive cleaning operations are at locations progressively closer to the filtered air source so that the part and the environment each become steadily cleaner. In laminar vertical flow clean rooms, the layout of the successive cleaning operations is not as critical. See ISO 14664 for further information.

## 7. Conditioning

7.1 Factors to consider before selecting cleaning methods include:

7.1.1 Type of contaminant, that is, inorganic, organic, particulate, film, or fluid,

7.1.2 Base material or coating of the part to be cleaned,

7.1.3 Initial condition of the part to be cleaned,

7.1.4 Required final cleanliness of the part,

7.1.5 Environmental impact and lawful disposition of hazardous waste products generated by the required cleaning method, solutions, and reagents used,

7.1.6 Cost effectiveness of the required cleaning method,

7.1.7 Effects of the selected cleaning methods on the part to be cleaned, such as mechanical, chemical, and thermal, and

7.1.8 Ease of cleaning (part configuration).

## 8. Cleaning Methods

### 8.1 General:

8.1.1 A cleaning method is the procedure(s) used to bring a cleaning agent into contact with all component surfaces to be cleaned, with the goal of removing contaminants. Cleaning materials and equipment for use in oxygen-enriched environments should begin with disassembly to the elemental or piece-part level as discussed in 6.1. When the component has been disassembled, parts should be grouped according to cleaning method. While the methods described apply to most metals, special precautions must be taken for nonmetals, which require special attention as discussed in 6.2.1 and 6.2.2.

8.1.2 Cleaning methods can be categorized as mechanical, chemical, or both. Some cleaning operations are enhanced by combining mechanical and chemical methods, such as mechanical agitation of a chemical solution.

**NOTE 1—Warning**—Both caustic and acid cleaning involve the use of hazardous materials and solutions. Full protective clothing, including gloves and face protection, should be worn by cleaning operators. Disposal of spent cleaning solutions should be conducted according to federal, state, and local regulations. The appropriate MSDS for the material must be reviewed and controls implemented before using hazardous materials.

8.2 *Mechanical Cleaning*—These methods use mechanically generated forces to remove contaminants from components. Examples of mechanical cleaning methods are abrasive blasting, grinding, tumbling, swabbing, and ultrasonication. Details of these and other methods are discussed below.

#### 8.2.1 *Abrasive Blast Cleaning*.<sup>7</sup>

8.2.1.1 Abrasive blast cleaning involves the forceful impingement of abrasive particles against surfaces to be cleaned to remove scale, rust, paint, and other foreign matter. The abrasive may be either dry or suspended in liquid. Various systems are used to propel abrasives, including airless abrasive blast blades or vane-type wheels, pressure blast nozzles, and suction (induction) blast nozzles. Propellant gases should be verified as oil-free.

8.2.1.2 Typical abrasive particle materials include metallic grit and shot, natural sands, manufactured oxide grit, carbide grit, walnut shells, and glass beads. The specific abrasive particle material used should be suitable for performing the intended cleaning without depositing contaminants that cannot be removed by additional operations, such as high velocity blowing, vacuuming, and purging.

8.2.1.3 Take care to minimize removal of the component parent material. This cleaning method may not be suitable for components or systems with critical surface finishes or dimensional tolerances.

8.2.1.4 In some cases, abrasive blast cleaning will induce residual compressive stresses in the surfaces of metallic components. Although this induced stress is beneficial in terms of fatigue strength, it may be detrimental to another of these component's material properties, such as magnetic and electrical characteristics.

**NOTE 2—Warning**—Protective gloves, aprons, face shields, and respiratory equipment are recommended unless the blast cleaning is performed inside a glove-box. The immediate health hazards are imbedding of stray abrasive particles in eyes and skin. The long-term hazard could include respiratory disorders caused by inhalation of fine particles.

#### 8.2.2 *Wire Brush or Grinding Cleaning*:

8.2.2.1 Wire brushing or grinding methods generally incorporate a power-driven wire or nonmetallic fiber-filled brush, or an abrasive wheel. These are used to remove excessive scale, weld slag, rust, oxide films, and other surface contaminants. Wire brushes may be used dry or wet. The wet condition results when the brushes are used in conjunction with alkaline cleaning solutions or cold water rinses.

8.2.2.2 These mechanical methods may imbed brush or grinding material particles in the cleaning surface. Cleaning brush selection depends on the component or system parent material. Nonmetallic brushes are suitable for most materials to be cleaned. Carbon steel brushes should not be used on aluminum, copper, and stainless steel alloys. Any wire brushes previously used on carbon steel components or systems should not be subsequently used on aluminum or stainless steel. The user should be aware that wire brushing and grinding can affect dimensions, tolerances, and surface finishes.

8.2.3 *Tumbling*—Sometimes called Barrel or Mass Cleaning, this procedure involves rolling or agitation of parts within a rotating barrel or vibratory tubs containing abrasive or cleaning solution. The container action, rotation, or vibration imparts relative motion between the components to be cleaned and the abrasive medium or cleaning solution. This method may be performed with dry or wet abrasives. The part size may vary from a large casting to a delicate instrument component, but mixing different components in one barrel should be avoided, as damage may occur from one component impacting on another of a different type. Barrel cleaning may be used for descaling, deburring, burnishing, and general washing. Some factors to consider in barrel cleaning are component size and shape, type and size of abrasive, load size, barrel rotational speed, and ease of component/abrasive separation.

8.2.4 *Swab, Spray, and Dip Cleaning*—Each of these methods of applying cleaning solutions to the component surfaces has its particular advantages. Swabbing is generally used on parts or components to clean small select areas only. Spraying and dipping are used for overall cleaning. These methods are generally used with alkaline, acid, or solvent cleaning methods discussed in later sections.

8.2.5 *Vacuuming and Blowing*—These methods remove contaminants from the component by currents of clean, dry, oil-free air or nitrogen. These methods may be used to remove

<sup>7</sup> For a more detailed discussion of abrasive blast cleaning, see Metals Handbook Desk Edition, 2nd Edition, Joseph R. Davis, Editor, American Society for Metals, Metals Park, OH, 1999.

loose dirt, slag, scale, and various particles, but they are not suitable for removing surface oxides, greases, and oils.

**8.2.6 “Pig” Cleaning**—Long continuous pipelines can be cleaned in situ using “pigs,” piston-like cylinders with peripheral seals that can be pushed through a pipeline using compressed gas pressure, typically nitrogen. Pigs may be equipped with scrapers or wire brushes, and pairs of pigs may carry slugs of liquid cleaning agents between them. Hence, a train of four pigs can transport three isolated slugs of solution through a pipeline to produce various levels of cleaning and rinsing. The mechanical and chemical suitability of the solvents, scrapers, and wire brushes should be ensured as detailed in **8.2.2** and **8.3**.

**8.2.7 Ultrasonic Cleaning**—Ultrasonic energy can be used with a variety of chemical cleaning agents to effect intimate contact between the part and the cleaning agent. Ultrasonic agitation aids removal of lightly adhered or embedded particles from solid surfaces. It is generally used in solvent cleaning of small parts, precious metal parts, and components requiring a very high degree of cleanliness. See Practice **G131** for an ultrasonic cleaning procedure.

### 8.3 Aqueous Cleaning:

**8.3.1** The following methods are based on achieving an interaction between the cleaning solution and the contaminant or component surface to effect easy removal of contaminant by subsequent mechanical methods. The interaction may involve surface activation, contaminant breakdown, oxide conversion, and hydrophobic or hydrophilic transformations. Water used for dilution and rinsing of chemical cleaning agents must be as clean or cleaner than the level of cleanliness desired and free of contaminants to prevent reactions with the cleaning agents. Water shall be of a grade equal or better to that specified in Specification **D1193**, Type II, without the silica analysis. Water with a higher specific resistance may be required for particular applications or cleaning systems.

**8.3.2 Hot-Water Cleaning**—Hot water cleaning removes gross organic and particulate contamination from parts by using low to moderate heat, detergent, and some mechanical agitation. Equipment used during hot-water cleaning may consist of a spray system or a cleaning vat with or without suitable agitation of the solution. Hot-water cleaning with detergent can be used where steam is not required to free and fluidize contaminants. Consideration should be given to the size, shape, and number of parts to ensure adequate contact between part surfaces and the solution. Solution temperature should be as recommended by the cleaning agent manufacturer. Water-soluble contaminants are best removed by prompt flushing with sufficient quantities of hot or cold clean water before the cleaning agents have time to precipitate. The parts are then dried by blowing with dry oil-free air or nitrogen, which may be heated to shorten the drying time.

**8.3.3 Steam Cleaning**—Steam cleaning removes organic and particulate contaminants from parts by using pressure, heat, and sometimes detergents. Some organics are removed by decreasing their viscosity, or “thinning” them with steam heat. Detergent may be added to disperse and emulsify organics, which allows rinsing of the contaminant by condensed steam. The system should provide control over steam, water, and

detergent flows to maximize efficiency of the detergent’s chemical action, the steam heat effect, and the steam jet’s scrubbing action.

**8.3.4 Caustic and Detergent Cleaning**—This method relates to the cleaning of vessels, piping systems, or components either externally or internally and uses water as the primary solvent. Synthetic detergents and surfactants are combined with additives such as pH buffers, inhibitors, saponifiers, emulsifiers, antifoaming agents, wetting agents, and others for beneficial effects.

**8.3.4.1** Caustic cleaning uses highly alkaline solutions to remove organic contamination such as hydrocarbon oils, grease, and waxes. Some common alkaline salts available for caustic cleaning are listed in **Table 2**. Prepared solutions can be used in static tanks or vessels for component immersion. Alternatively, solutions can be pumped or jetted onto or through components. Depending on the detergent used, solutions may be alkaline, nontoxic, biodegradable, or noncorrosive. Some detergents may be toxic or corrosive, and detergent properties should be verified by the manufacturer or supplier. See Guide **G127** for selection criteria. The cleaning solution can be applied by spraying, immersing, or hand swabbing. Normally, caustic cleaning solutions are applied at temperatures up to 180 °F [82.2 °C]. It is important that the cleaning solution reach all areas of the part to be cleaned. The cleaning solution can be reused until it becomes ineffective as determined by pH or contaminant concentration analysis. Experience may establish a contaminant level of the cleaning solution above which a surface cannot be acceptably cleaned.

NOTE 3—Caution: Alkaline cleaners attack aluminum.

**8.3.4.2** Aqueous systems have few problems with worker safety compared to most other solvents. They are not flammable or explosive, and toxicity is low for most formulations. Aqueous systems can be designed to remove particulate and film contamination. They are especially good for removing inorganic or polar materials. Aqueous cleaning functions by several mechanisms other than solvency, including saponification, displacement, emulsification, and dispersion. Ultrasonics are especially suited for aqueous solvents.

**8.3.4.3** The part must be thoroughly rinsed to prevent the cleaning solution and contaminants from redepositing on the surface. The surface must not be allowed to dry between the cleaning and rinsing phases. Frequently, some type of water rinsing helps to remove the cleaning solution and aids in the drying process. Parts with small crevices and blind channels

**TABLE 2 Common Alkaline Salts (see 8.3.4.1 and 9.4)**

IUPAC Name <sup>A</sup>	Formula	Common Name
Sodium hydroxide	NaOH	Caustic soda Lye
Sodium metasilicate	Na <sub>2</sub> SiO <sub>2</sub>	Sodium silicate Water glass
Sodium carbonate	Na <sub>2</sub> CO <sub>3</sub>	Soda ash
Sodium tetraborate decahydrate	Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> ·10H <sub>2</sub> O	Borax
Sodium orthophosphate	Na <sub>2</sub> PO <sub>4</sub> ·12H <sub>2</sub> O	Trisodium phosphate (TSP) Sodium phosphate tribasic
Sodium pyrophosphate	Na <sub>4</sub> P <sub>2</sub> O <sub>7</sub> ·10H <sub>2</sub> O	Tetrasodium pyrophosphate Sodium polyphosphate

<sup>A</sup> According to the International Union of Pure and Applied Chemistry.

**TABLE 3 Alkaline Chemical Cleaning Materials (see 8.3.4.3)**

Metal	Reason for Cleaning	Cleaning Chemicals <sup>A</sup>	Other Treatment <sup>B,C</sup>
Carbon and low alloy steels	Removal of heavy soil, grease, and oil	Mixtures of sodium hydroxide, carbonates, phosphates and silicates, and synthetic wetting agents	Solutions should not be allowed to dry on the part and must be thoroughly rinsed
Austenitic stainless steel	Removal of heavy soil, grease, light oils, and cutting fluid	Mixtures of sodium hydroxide, carbonates, phosphates and silicates, and synthetic wetting agents	
Copper and alloys	Removal of grease, lubricating oil, drawing compound, oxide, metallic particles, or other contaminants	Mixtures of sodium hydroxide, polyphosphates, silicates, carbonates, and wetting agents	Usually bright dipped in dichromate acid solution
Aluminum and alloys	Removal of brazing flux Removal of grease, oil, and oxide	Hot water Sodium hydroxide, sodium phosphate, and sodium carbonate for etching Sodium carbonate, sodium silicate, sodium pyrophosphate, and sodium metasilicate for nonetching	Dilute nitric acid dip to remove smut

<sup>A</sup> The manufacturer's specification for application of the cleaning agent shall be strictly enforced.

<sup>B</sup> *Postchemical Cleaning Treatment*—After cleaning using alkaline chemicals, all components shall be thoroughly rinsed, preferably using hot flowing water to aid drying, unless otherwise specified by the cleaning material supplier. Some components require treatment by using neutralizing solutions after certain cleaning treatments.

<sup>C</sup> Thorough rinsing is necessary to avoid stress corrosion risk.

may be difficult to clean because of the relatively high surface tension and capillary forces of water-based cleaners. Some aqueous cleaner residues can be difficult to rinse from surfaces; nonionic surfactants are especially difficult to rinse. A method of determining when rinsing is complete is to monitor the used rinse water until a pH of  $\pm 0.2$  of the starting water pH is achieved. Parts with complex geometries may be difficult to dry. Clean, dry, oil-free air or nitrogen, heated if necessary, may be used for drying. Alternatively, vacuum may be used to achieve desired dryness. Table 3 gives general recommendations for alkaline cleaning. This table lists the metallic material, type of contaminant to be removed, and the alkaline solution used.

#### 8.3.4.4 Drying:

(1) When aqueous cleaning is used on oxygen system components, rinsing and drying are of critical concern. Drying is the removal of water or other solvents from critical surfaces. The actual process of drying involves a change of state and requires energy. The amount of energy depends on many factors such as the solvent to be evaporated, the configuration of the hardware, the temperature of the operation, and the conductivity of the liquid and the hardware. The heat of vaporization for water is an order of magnitude higher than that for some common chlorofluorocarbon solvents. The removal of vapor is also critical in drying, and a means for removal of vapor must be provided. This is usually accomplished with a moving dry gas purge.

(2) In selection of a drying process, consideration must be given to the level of dryness required. The user should evaluate each method for the specific application intended. There are three basic water removal methods commonly used:

(a) *Physical*—actual removal of liquid such as scraping, wiping, centrifuging, or blowing.

(b) *Solvent*—wetting the part with a higher vapor pressure liquid to displace the water, such as with alcohol or hydrofluorocarbons.

(c) *Evaporation*—adding energy and physically removing the vapor such as drying by oven, air, or purge.

(3) Small- and medium-size hardware drying is often done in filtered gas-purged ovens. System and tank drying may be

achieved by purging with a clean, flowing, dry gas, usually nitrogen or air. Care must be taken in measuring the dew point of a flowing gas. It is possible to inadvertently measure the dryness of the purge gas only. To sample correctly, a lock-up and pressurization procedure, with a time allowance interval, is necessary. Items dried with a flowing, heated, dry gas purge are usually considered dry when the dew point of the exit gas is within 5 °F [3 °C] of the purge gas.

(4) Dryness is measured in many ways:

(a) Relative humidity,

(b) Dew point,

(c) Unit mass of water per unit mass of gas (ppm),

(d) Unit volume of water per unit volume of gas (v/v), and

(e) Moles of water per moles of air.

(5) Oxygen systems are typically considered dry at equilibrium exit gas dew points of from 0 °F [-18 °C] to as low as -70 °F [-57 °C] depending on the specific application. The choice depends on many variables such as cost, time, use temperature, and effects of moisture on components. Industrial gases are easily obtained with dew points of -40 °F [-40 °C], a common specification level for oxygen system dryness.

#### 8.3.5 Semiaqueous Cleaning:

8.3.5.1 Semiaqueous cleaning uses hydrocarbon-water emulsions to remove heavy contaminants from part surfaces with organic solvents dispersed in an aqueous medium by an emulsifying agent. The cleaning action of emulsion cleaners combines the advantages of both the aqueous and organic phases.

(1) Many emulsion cleaners are commercially available and are composed of petroleum-derived solvents and surfactants that render them emulsifiable. Some emulsion cleaners tend to separate into individual solutions if left standing for extended periods, and it may be necessary to periodically agitate them so that they remain emulsified. It is important that two-part mixtures are not allowed to separate, to preclude only part of the mixture being removed from the system. Emulsion cleaners are normally applied to parts by soaking, spraying, or swabbing. Emulsion cleaners must be removed by rinsing and subsequent cleaning operations.

8.3.5.2 One type of semiaqueous material is a water emulsion with natural citrus and pine-based terpenes. Semiaqueous cleaners are either emulsified in water and applied in a manner similar to standard aqueous cleaners or they are applied in concentrated form and then rinsed with water. Semiaqueous formulations are compatible with most metals and plastics. They have good cleaning ability, especially for heavy grease, tar, wax, and hard to remove soils. The semiaqueous formulations are considered nonflammable in bulk but can be flammable as a mist. Proper equipment design is essential to minimize risk from flammable mists. Some formulations can auto-oxidize into an undesirable condition. Material must be verified with the supplier.

8.3.5.3 The cleaning solution must be thoroughly rinsed from the part to prevent contaminants from redepositing on the surface. The surface must not be allowed to dry between the cleaning and rinsing phases. Semiaqueous residues are especially difficult to rinse from surfaces. A more thorough analysis than rinse water pH may be required to determine rinse phase completion. Parts with complex geometries may be difficult to dry. Clean, dry, oil-free air or nitrogen, heated if necessary, may be used for drying. Alternatively, vacuum may be combined with purging to achieve desired level of dryness. Care must be used to prevent buckling from external pressure when vacuum is applied.

#### 8.3.6 Acid Cleaning:

8.3.6.1 Acid cleaning is a process in which a solution of mineral acid, organic acid, or acid salt (often in combination with a wetting agent and detergent) is used to remove oxides, oils, and other contaminants from parts, with or without the application of heat. Acid cleaning must be carefully controlled to avoid damage to the part surfaces, such as undesired etching or pickling. The type of cleaning agent selected will depend on the material or part to be cleaned. The following is a general guide for the use of acid cleaning.

8.3.6.2 Phosphoric acid cleaning agents can be used for most metals. These agents will remove oxides, light rust, light soils, and fluxes.

8.3.6.3 Hydrochloric acid cleaning agents are recommended only for carbon and low alloy steels. These agents will remove rust, scale, and oxide coatings and will strip chromium, zinc, and cadmium platings. Certain acidic solutions, including hydrochloric or nitric acids, should contain an inhibitor to

prevent harmful attacks on base metals. Hydrochloric acid should not be used on stainless steel since it may cause stress corrosion or stress corrosion cracking.

8.3.6.4 Chromic and nitric acid cleaning compounds are recommended for aluminum and copper and their alloys. These compounds are not true cleaning agents, but are used for deoxidizing, brightening, and for removing black residue that forms during cleaning with an alkaline solution. Some compounds are available as liquids, and others as powders. They are mixed in concentrations of 5 to 50 % in water, depending on the cleaning agent and the amount of oxide or scale to be removed.

8.3.6.5 Acid cleaning requires a storage or an immersion tank, recirculation pump, associated piping, and valving compatible with the cleaning solution. Common techniques for acid cleaning are immersion, swabbing, and spraying. Acid cleaning compounds should not be used unless their application and performance are known or are discussed with the cleaning compound manufacturer. The manufacturer's recommendations regarding concentration and temperature should be followed for safe handling of the cleaning agent. After acid cleaning, surfaces must be thoroughly rinsed with water equal to that described in 8.3.1 to remove all traces of acid and then thoroughly dried after the final water rinse. To minimize staining, do not allow surfaces to dry between successive steps of the acid cleaning and rinsing procedure. A neutralizing treatment may be required under some conditions. Neutralization must be followed by repeated water rinsing to remove all traces of the neutralizing agent. If drying is required, it can be completed with heated or unheated, dry, oil-free air or nitrogen. Table 4 gives typical acid solutions for cleaning various types of metallic materials.

8.3.7 Solvent Cleaning—This cleaning or degreasing method was once considered to be the principal procedure for removal of soluble organic contaminants from components to be used in oxygen service and was suitable for use with most metals. The use and attractiveness of chlorinated solvents as cleaning solutions, however, have been limited by environmental concerns and legislative restrictions. Chlorinated solvents are being replaced by aqueous or semiaqueous detergents or emulsion solutions, often in conjunction with deionized water as part of the process. Alcohols, ethers, and other specialized solvents are used in unique cleaning applications where their

**TABLE 4 Acid Chemical Cleaning Materials (see 8.3.6.5)**

Metal	Reason for Cleaning	Cleaning Chemicals <sup>A</sup>	Other Treatment <sup>B</sup>
Carbon and low alloy steels	Removal of scale and oxide films (pickling)	Hydrochloric or sulfuric acid and wetting agents	Dilute alkali dip to neutralize acid or treatment with inhibitor Light scrubbing action helpful
	Removal of light rust Removal of grease, oil, or drawing compound	Citric, sulfuric, and phosphoric acids Phosphoric acid and synthetic detergents mixture	
Cast iron	Removal of oxide	Chromic and sulfuric acid	Nitric acid solution used to brighten
Austenitic stainless steels	Removal of oxide, tarnish and scale and metallic deposits/contaminants	Chromic, sulfuric, and hydrofluoric acid, or nitric, hydrofluoric, and phosphoric acids	
Copper and alloys	Removal of scale and oxide (pickling)	Hydrochloric or sulfuric acid	
	Brightening	Sulfuric, nitric, and hydrochloric acids	
Aluminum and alloys	Removal of oxide (etch cleaning)	Nitric acid solution used to brighten	Hydroxide solutions

<sup>A</sup> The manufacturer's specification for application of the cleaning agent should be strictly observed or the properties of the metals can be impaired. Time, temperature, and concentrations are very important.

<sup>B</sup> *Postchemical Cleaning Treatment*—After acid cleaning, all components should be thoroughly rinsed, preferably using flowing hot water to aid drying, unless otherwise specified by the cleaning material supplier. Some components require treatment with neutralizing solutions after certain cleaning treatments.

hazards are warranted due to process restrictions. A list of common solvents appears in 11.4.2 and Table 5. This method is limited by the ability of the solvent to reach and dissolve any contaminants present. Before starting any cleaning operation, a reference sample of fresh clean solvent should be set aside to use as a base reference. At intervals throughout the procedure, samples of used solvent can be compared with the reference sample to determine the level of contamination. Methods of determining contamination can be by comparison to the color of the reference sample, by fluorescence under ultraviolet light, by analysis, or by evaporation. Clean glass bottles must be used to hold samples.

8.3.7.1 After completion of any solvent cleaning method, all gross residual cleaning fluid must be drained from the component to prevent drying in pools. The component shall then be purged and dried with heated dry, oil-free air or nitrogen. Small components may be air dried if appropriate, so long as they do not become recontaminated.

8.3.7.2 Solvent cleaning may be performed using any of the methods previously discussed such as swabbing and spraying. Components and disassembled parts can also be cleaned by immersion in a solvent tank and applying agitation. The process can be improved by the use of ultrasonic cleaning techniques. Cleaning by forced circulation of a liquid solvent flow through the component can also be carried out. The duration of cleaning by circulation shall be continued using clean solvent until the used solvent emerges from the component as clean as the reference sample.

8.3.7.3 Solvents frequently require inhibitors to control corrosion reactions. The addition of inhibitors may require monitoring to ensure continued effectiveness. This method is often applied to assemblies that cannot be disassembled, to large size components, to prefabricated circuits, and pipe-works.

### 8.3.8 Solvent Cleaning Hazards:

8.3.8.1 **Warning**—Take care that generous ventilation is provided in solvent cleaning areas to prevent workers from breathing excessive amounts of solvent vapor or decomposition products. Vapor from any halogenated solvents is a powerful anesthetic. Inhaled in small quantities, it will cause drowsiness. In large quantities, the vapor can cause unconsciousness and ultimately death.

8.3.8.2 Chlorinated or fluorinated solvents may decompose in the presence of heat sources greater than 392 °F [200 °C], ultraviolet rays, and atmospheric humidity to form toxic gases, such as phosgene.

8.3.8.3 It is important to ensure that parts to be welded or heated are totally free of solvent. Smoking and the performance of any operation involving the use of flame, arc, or other

heat source higher than 392 °F [200 °C] should be prohibited in the vicinity of solvent vapor. Exposure of the solvent to daylight over a prolonged period may cause decomposition.

8.3.8.4 Solvent containers should not be left in working areas without suitable securely fitted lids or caps. Skin contact should be avoided by wearing protective clothing. Solvents should be carried only if contained in suitable properly labeled containers.

8.3.8.5 Federal, state, local, or insurance regulations may require that precautions such as electrically grounding containers, remote storage, and spill containment structures be provided. Some solvents are flammable, toxic, or carcinogenic, and manufacturer’s recommended safety precautions should be followed. Also, compliance to federal, state, and local regulations may be required. Manufacturers of ultrasonic cleaning tanks and associated equipment issue recommendations on their safe operation. Operators shall comply with the manufacturer’s recommendations. A material Safety Data Sheet is required for each chemical used.

**NOTE 4—Warning**—Aluminum and its alloys have been known to react vigorously with chlorinated hydrocarbon solvents to produce hydrochloric acid vapor, which is both toxic and corrosive. The conditions under which these reactions occur are not well known. This particularly occurs on aluminum particles such as swarf or chips from machining or cutting processes.

8.3.8.6 When using solvents to clean aluminum, the following should be observed:

(1) Ensure that only inhibited commercial grade solvents, specifically designated as degreasing solvents, are used for aluminum and its alloys. These solvents should be periodically checked to monitor the inhibitor level.

(2) If a degreasing tank is used, gently place components into the degreasing tank to avoid rupturing the protective oxide film.

(3) Ensure that the material being cleaned is free from particles such as swarf or dust. Aluminum fines, chips, or powders should never be allowed to contact the solvent.

(4) Aluminum parts should never be left in contact with degreasing solvents for extended periods of time since the solvent can react with the metal under such conditions.

8.4 *Vapor Degreasing*—Vapor degreasing is the removal of soluble organic materials from part surfaces by the continuous condensation of solvent vapors on the cold part and their subsequent washing action. However, the use and attractiveness of chlorinated solvents as cleaning agents has been limited by environmental concerns and legislative restrictions. Chlorinated solvents are being replaced with nonrestricted replacements; selection of replacement agents is discussed in Guide G127. Vapor degreasing equipment consists of a vaporizer for generating clean vapors from a contaminated solvent and a container for holding the parts in the vapor phase. DO NOT use refrigerant grade solvents, as they have been known to contain oils. Some of these solvents used are flammable in air under certain conditions and have varying degrees of toxicity; therefore, caution should be exercised in their use. Part temperature must be below the boiling point of the solvent so that solvent vapors will condense and wash down by gravity over part surfaces. The component should be positioned and

**TABLE 5 Common Solvents (see 8.3.7)**

Chemical Class	Common Examples
Hydrochlorofluorocarbons	Asahiklin AK 225
Hydrofluorocarbon	DuPont Vertrel XF DuPont Vertrel MCA
Hydrofluoroether	3M HFE 7100 3M HFE 71DE



connected so that the condensate will drain from the ports. Continuous circulation of the condensate and its transport back into the vaporizer will carry the dissolved contaminants into the vaporizer where they will remain. No further cleaning will occur after the part temperature reaches the vapor temperature.

**NOTE 5**—Caution: Highly flammable materials such as gasoline, kerosene, naphtha, or paint thinners should not be used for any chemical cleaning or rinsing. Some plastic tubing or seals used in cleaning equipment may undergo chemical extraction by the solvent, and which would be deposited on the surface intended to be cleaned. Nylon and polytetrafluoroethylene (PTFE) tubing are satisfactory with many frequently used solvents. The precautions stated in 8.3.8.6 should be observed in cleaning aluminum and its alloys.

### 8.5 Purging:

8.5.1 It is very important to purge the component to ensure that all residuals from previous cleaning operation(s) are removed before subsequent cleaning operations or final packaging occur. This can be accomplished by rinsing, drying, and blowing. Rinsing may be dependent upon the cleaning solutions used, but in general filtered water may be used. Drying may be done by the application of heat to the component by ovens and infrared lights, or by blowing with clean, oil-free, dry air. Removal of solvent at elevated temperatures requires additional attention because solvents are more likely to attack the component surfaces or to decompose and deposit undesirable films on the component under such conditions. Environmental law may require passing exhaust gases through a charcoal or absorbant bed to remove solvent atmospheres before release to atmospheric exhaust. It is important that the purging medium have a cleanliness level greater than the desired cleanliness level of the component.

8.5.2 A more critical purging is performed using clean, dry, oil-free nitrogen gas. This may require dryness verification by measuring the dew point of the effluent drying gas. Final duration and the type and number of purging operations depend on the component to be cleaned, the cleaning methods used, and the final application.

## 9. Cleaning Procedures

9.1 A cleaning program should be selected that results in an increase in the degree of cleanliness of the component after each cleaning operation. It, therefore, becomes a matter of processing the component through a series of cleaning methods, or cycles within a single method, or both, in order to achieve the desired final degree of cleanliness.

9.2 It may be possible to obtain the desired degree of cleanliness in a single operation, but many cleaning operations are required to progress in several stages, such as a precleaning or initial cleaning stage, an intermediate cleaning stage, and a final cleaning stage. Each cleaning stage must be isolated from previous stages by appropriate rinsing, drying, and purging operations.

### 9.3 Precleaning:

9.3.1 Precleaning should be used to remove gross contaminants, such as excessive oxide or scale buildup, large quantities of oils and greases, and inorganic particulates.

9.3.2 Precleaning reduces the quantity of contaminants, thereby increasing the useful life and effectiveness of the cleaning solutions used in subsequent cleaning operations. The

cleaning environment and handling procedure used for all precleaning operations are not critical, but users are encouraged to be aware of, and follow, all related safety practices.

9.4 *Intermediate Cleaning*—The intermediate cleaning stage generally consists of subjecting the part to caustic or acid cleaning solutions designed to remove solvent residues and residual contaminants. The cleaning environment and handling procedures used for intermediate cleaning operations are more restrictive than those used for precleaning. The cleaning environment and solutions must be appropriately controlled in order to maximize solution efficiency and to minimize introducing contaminants, compromising subsequent final or precision cleaning operations. A list of common alkaline salts and detergents is given in **Table 2**.

### 9.5 Final Cleaning:

9.5.1 When components are required to meet very high degrees of cleanliness, such as in nuclear, space, and electronic applications, they are subjected to a final cleaning stage. This final stage involves the removal of minute contaminants and is generally performed with chemical cleaning methods. At this stage of cleaning, protection from recontamination of the component by the cleaning solutions or the environment becomes critical. In order to obtain very high degrees of cleanliness, the cleaning environments may require strict controls, such as those found in classified clean-rooms.

9.5.2 The final cleaning stage incorporates expanded drying and purging operations with a packaging program to protect the component from re-contamination.

## 10. Cleanliness Requirements

### 10.1 The Need for Cleanliness:

10.1.1 Scrupulous cleaning is the most fundamental fire-safety measure applied to oxygen-handling systems. One may not have to alter polymers or metals in some systems of low severity, but any system that is exposed to oxygen or oxygen-enriched service will require scrupulous cleaning. Various cleanliness requirements have been followed by different organizations over the years. These levels have treated liquid contaminants (basically oils and greases) and solid contaminants (basically particulates) separately.

10.1.2 *Fluids and Greases*—**Table 1** lists several oil-film specifications that have been published through the years, ranging from 0.013 to 100 mg/ft<sup>2</sup> [0.14 to 1080 mg/m<sup>2</sup>]. Today, the extremes of this range do not appear to be in use.

10.1.2.1 Among the factors involved in choosing the degree of cleanliness required for surface films are such things as: film flammability, film ignitability, film sensitization of other materials, film migration, and accumulation (including tendencies to flow, to evaporate and condense at elevated temperature, and to chip at low temperatures) **(9)**.<sup>8</sup>

10.1.2.2 When assessing contaminant type (see 7.1) and final cleanliness level (see 7.1.4), it is important to consider potential ignition hazards that could be active in a system. Adiabatic compression is the primary ignition mechanism of

<sup>8</sup> The boldface numbers in parentheses refer to the list of references at the end of this standard.

oils and greases, having produced ignition experimentally (10) at approximately  $6 \text{ mg/ft}^2$  [ $65 \text{ mg/m}^2$ ]; also, migration and collection of nonviscous oils appears to occur above  $\sim 20 \text{ mg/ft}^2$  [ $\sim 220 \text{ mg/m}^2$ ] (9). This suggests  $6 \text{ mg/ft}^2$  [ $65 \text{ mg/m}^2$ ] may be the highest conservative limit that may be applicable for incompatible oils in severe service. In a system that does not experience rapid compression, this conservative limit might be extended to  $20 \text{ mg/ft}^2$  [ $220 \text{ mg/m}^2$ ] on small components or regions that are difficult to clean whether they are part of larger systems or not. However, where surfaces are large, lower levels of maximum fluid contamination are usually needed. A recent CGA pamphlet (7) recommends that oil film contamination on structured distillation column packing (that is a very high surface area application) be limited to 4.6 to  $9.3 \text{ mg/ft}^2$  [ $50$  to  $100 \text{ mg/m}^2$ ] with the upper limit applied to local regions and the lower limit taken as a system overall average. This level takes into account the high surface area (resulting in a limit less than  $20 \text{ mg/ft}^2$  [ $220 \text{ mg/m}^2$ ]), but also factors in material compatibility considerations, knowledge of the specific contamination that might be present, and migration factors that allow a higher oil film limit than would otherwise be acceptable.

10.1.3 *Solids and Particulates*—Solids and particulates should be controlled in order to reduce the particle impact ignition hazard and to better ensure component reliability and functionality. Bankaitis and Schueller (6) list several limits which have been applied in government and industry to control solids and particulate contamination.

10.1.3.1 Factors involved in choosing the degree of cleanliness required for particles are such things as particle flammability, ignitability, size, shape, and migration tendency (including fluidization) (8), critical sealing surfaces, and tolerances within the equipment that can be affected by particles.

10.1.4 *Fluids Versus Solids*—Through the years, more attention has been focused on fluid oil films than on solid contaminants. This is due to several reasons. Oil films tend to be more easily ignited. They migrate. They vaporize. They are more likely to be present in greater total amounts. Also, when an oil film is scrupulously removed, it is likely that there will be little if any unacceptable particulate contaminant remaining. Further, many solid particulates are inert and present more of a mechanical problem than a fire risk.

## 10.2 *Technical Practicalities:*

10.2.1 *Cleaning Capabilities*—When the present-day cleaning methods described in this guide are carefully used, it is realistic to achieve oil film residues that are no more than a very few  $\text{mg/ft}^2$  (for example, 1 to 3), and typically, cleanliness levels of less than  $1 \text{ mg/ft}^2$  [ $11 \text{ mg/m}^2$ ] or less will result. Very few systems will demand cleanliness better than this level. Further, for most systems, the time or economic saving that can be had with less scrupulous use of these conventional methods is often not great. Therefore, there are only a few systems with a practical or economic incentive to establish target thresholds above or below this level, and they are very few.

10.2.2 *Cleanliness Verification*—Traditionally verification of cleanliness of oxygen systems has relied on spot and sometimes general inspection of surfaces after they are cleaned. However, one can also “verify” cleanliness by estab-

lishing the suitability of the cleaning procedure and the diligence of its use, as well. Common inspection techniques that are practical in the field have always been limited in their ability to conveniently detect oils to the levels that are achievable with scrupulous cleaning and that are often needed for safety. Indeed, such common inspection methods as “black” (ultraviolet) light examination may not detect some oils that are far in excess of safe levels. In general, this type of verification cannot employ the awkward or cumbersome high-tech laboratory methods such as solvent extraction/evaporation, or loss on ignition methods. Such post-cleaning inspections are nonetheless beneficial, because they establish an atmosphere of diligence and can detect when serious breaches of good cleaning practice occur. Doubtless, however, a greater margin of the safety that has resulted in oxygen systems in the past has been due to diligent cleaning practices with effective cleaning agents than due to inspection. Because of the change in cleaning process resulting from the loss of cleaning materials due to environmental and toxicological regulations, it is much more difficult to be confident that systems are adequately clean despite verification of cleanliness through visual inspection of equipment after it has been cleaned. Hence, in the future, there will be increasing need to practice the world-wide quality principle of prevention: focusing on qualifying appropriate cleaning procedures (perhaps with high technology laboratory verification methods not suited to general inspection use) and using these procedures for careful cleaning of the system rather than focusing on final inspection with common instruments such as ultraviolet light. However, in many cases, the use of final spot- or random-sample inspections (statistical process control) to detect when the cleaning system has broken down will continue to have value.

## 10.3 *Suggested Surface-Film Cleanliness Limits:*

10.3.1 *General Conservative Target*—For the majority of systems, a target cleanliness goal of about  $1$  to  $5 \text{ mg/ft}^2$  [ $11$  to  $55 \text{ mg/m}^2$ ] or less of nonapproved oil or grease film is suggested. This appears to be conservative for even the more undesirable contaminants.

10.3.2 *General Upper-Limit Target*—A more liberal target allowance up to perhaps,  $20 \text{ mg/ft}^2$  [ $220 \text{ mg/m}^2$ ] may be acceptable and conservative, especially in systems not susceptible to rapid pressurization or in small components that are particularly difficult to clean and inspect. This level appears to control the migration hazard of even fairly light oils.

10.3.3 *Exceptional Cases*—To exceed a  $20 \text{ mg/ft}^2$  [ $220 \text{ mg/m}^2$ ] level, one must consider both the severity of the system and the nature of the contaminant. The adoption of a more liberal allowance should be justified by a review of the hazards, risks, and consequences involved, especially the prospect of rapid compression of the oxygen. Those portions of a system of primary concern for cleaning are always the high-risk areas of high velocity regions (such as valve seats), sumps (where debris may collect or solvent may evaporate and concentrate solutes), and dead ends (where heat of compression is most likely). One strategy can be to allow those areas that may not be quite as clean and that cannot be inspected reasonably with current techniques to be offset somewhat by those more critical areas that achieve or exceed the target