

CGA G-4.1—2018
**CLEANING OF EQUIPMENT FOR
OXYGEN SERVICE**
SEVENTH EDITION

PREFACE

As part of a program of harmonization of industry standards, the Compressed Gas Association (CGA) has published [CGA G-4.1](#), *Cleaning of Equipment for Oxygen Service*, jointly produced by members of the International Harmonization Council.

This publication is intended as an international harmonized standard for the worldwide use and application of all members of the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Each association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

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Work Item 14-020
Atmospheric Gases and Equipment Committee

NOTE—Due to the extensive changes in this document, technical changes from the previous edition are not identified.

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1 Introduction

Since the early days of the industrial gases industry, it has been recognized that maintaining cleanliness of components in contact with oxygen is essential to avoid ignition of components or systems. Oxygen is not flammable but supports and accelerates combustion of most materials used in oxygen systems. Recognition of oxygen's reactivity led to stringent requirements for cleanliness of equipment in oxygen service.

In the past, recommended oxygen service cleaning agents included chlorofluorocarbons. Increasing concerns about the adverse environmental effects and health concerns of these cleaning agents led to restrictions and, in many cases, prohibitions on their use. As a result, alternative cleaning agents and methods have been developed to achieve the required levels of oxygen cleanliness.

This publication has been prepared by a group of experts in industrial gases technology or oxygen equipment and is based on currently available technical information and experience. It provides knowledge on the cleaning, inspection, and packaging and handling of equipment used in oxygen service.

2 Scope and purpose

2.1 Scope

This publication describes the cleaning methods and requirements for equipment used in the production, storage, distribution, and use of liquid and gaseous oxygen to reduce the risk of fire, explosion, or promotion of combustion. Cleaning in accordance with this publication is required for all surfaces in contact with a gas or liquid that has an oxygen concentration greater than 23.5%. Examples of such equipment include stationary storage tanks, road tankers, and rail cars; pressure vessels such as heat exchangers and distillation columns; compressors and pumps; and associated piping, valves, and instrumentation. However, the cleaning methods and requirements are not limited to this equipment. With modifications, these methods may be used for cleaning other oxygen and oxidizer (e.g., fluorine, nitrogen trifluoride, nitrous oxide) service equipment such as cylinders, cylinder valves, cylinder regulators, welding torches, and pipelines where regulatory requirements do not specify cleaning methods.

This publication does not replace or supersede any regulatory cleaning requirements specified by a national authority. For example, U.S. Department of Transportation (DOT) aluminum alloy oxygen cylinders shall be cleaned to the requirements of the Title 49 of the *U.S. Code of Federal Regulations* (49 CFR) Part 173.302(b)(3) [1].¹

2.2 Purpose

Oxygen equipment and systems including all components and their parts shall be cleaned to remove contaminants before the introduction of oxygen. Contaminants include both organic and inorganic material such as oils, greases, markings from crayons or other markers, thread lubricants, paint, cleaning agents and their residue, weld spatter and slag, rust and scale, metal particles, sand, dirt, lint, fiber, rags, paper, wood, coal dust, and other foreign materials that if not removed could cause combustion in an oxygen atmosphere.

This publication presents methods for cleaning oxygen service equipment. These cleaning methods and subsequent inspections result in the degree of cleanliness required for the safe operation of oxygen service equipment. Suggested levels of maximum allowable contamination and ways of determining if a component or system is clean for oxygen service are given along with requirements for keeping such equipment clean until it is placed into service.

Cleaning a component or system for oxygen service involves the removal of contaminants including the surface residue from manufacturing, hot work, and assembly operations as well as the removal of all cleaning agents and the prevention of recontamination before final assembly, installation, and use.

The removal of contaminants can be accomplished by cleaning all parts and maintaining this condition during construction, by cleaning the system after construction, or by a combination of the two.

¹ References are shown by bracketed numbers and are listed in order of appearance in the reference section.

3 Definitions

For the purpose of this publication, the following definitions apply.

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 Contamination

Unintended organic and inorganic material that if not removed can contribute to combustion in an oxygen atmosphere.

3.2.2 Detergents

Surfactants, with or without alkaline or acid builders, and other organic and inorganic additives.

3.2.3 Dry, oil-free air or nitrogen

Air or nitrogen with a dew point of -40°F (-40°C) or less and an oil content of 5.0 mg/m^3 or less [2].

3.2.4 Fiber

Particulate matter with a length of 100 microns or greater and a length to width ratio of 10:1 or greater [3].

3.2.5 Oxygen

Gas or liquid that contains more than 23.5% oxygen by volume (with the remainder of its components being inert).

3.2.6 Particle, particulate

General term used to describe a finely divided solid or organic or inorganic matter [3].

3.2.7 Solvent flash point

Temperature at which a solvent emits sufficient vapor to form an ignitable mixture with air near the surface of the liquid.

3.2.8 Water

Potable water.

NOTE—Some applications could require a higher quality water to achieve or maintain the desired cleanliness and/or to avoid corrosion.

4 Planning requirements

4.1 Precautions

A risk assessment that considers the properties of the cleaning agent, type of cleaning method, and the experience and training of the personnel shall be conducted in order to define appropriate control measures including disposal of cleaning agents. When an installed component or system needs to be cleaned in the field, there could be circumstances that require additional levels of expertise and/or approval of written procedures.

Cleaning system equipment such as storage containers, pumps, hoses, piping, and valves shall be compatible with the cleaning agent and method being used.

Personnel performing work shall wear clean work clothing (uncontaminated by oil, grease, or dirt). Only clean hands or gloves that are free of lint, fibers, powder, and uncontaminated by oil or grease are allowed. Items contaminated when used for other services such as automotive maintenance or fueling shall not be used in oxygen service (for example, clothing and gloves).

Review the applicable safety data sheet (SDS) for any hazards associated with the cleaning agent being considered.

The user shall take all required precautions to avoid the asphyxiation hazard that could result from purge gas used to dry or inert the equipment being cleaned [4].

4.2 Supervision

An individual skilled in the techniques required for oxygen service cleaning shall be responsible for monitoring the cleaning operation and for determining if a component or system is clean for oxygen service. Where piping systems with multiple branches are involved, it is important that the cleaning procedures are well established, integrated with the sequence of construction operations, and precisely followed since it might not be possible to completely inspect such a system for cleanliness after construction and final cleaning.

4.3 Selecting cleaning agents and methods

Initially, the contaminant type, possible location, and degree of contamination should be evaluated to decide on the cleaning agent and the most appropriate methods of cleaning and inspection. In addition, the arrangement of equipment to be cleaned shall be analyzed so that cleaning and inspection methods can be adjusted to make sure that dead ended locations and possible traps are cleaned. Selection of the appropriate method of cleaning shall be determined, in part, to meet the final level of cleanliness required in Section 9.

Any time a cleaning agent is used, attention shall be given to ensure that the cleaning agent is compatible with all wetted parts. Of particular concern is the compatibility of cleaning agents with the component materials including gaskets, soft goods, sealants, packing, and instrumentation. Also important is the compatibility of the cleaning agent with the storage and transfer items it will contact such as storage bottles, tubing, piping, pumps, filters, etc. Such storage and transfer equipment should not only be compatible with the cleaning agent, but also clean so as not to contribute any additional contamination to the process. Check with equipment manufacturers and product literature regarding material compatibility with cleaning agents. Besides obvious compatibility concerns that include chemical reactions, consideration shall be given to systems under pressure and the choice of cleaning agents. Although some cleaning agents do not appear to have a harmful effect on materials, they could have a negative impact on materials' properties that adversely affects its ability to contain pressure or perform as intended. Under such circumstances, the equipment manufacturer and the product literature shall be consulted for the recommended choice of cleaning agents.

The cleaning of completely assembled equipment or piping systems should be avoided to prevent the cleaning agent from being retained in the equipment leading to potential violent reactions in oxygen service. All equipment or piping systems should be cleaned prior to assembly, where possible.

Characteristics to be considered when selecting cleaning agents include:

- good degreasing properties;

- easily removable;
- noncorrosivity;
- compatibility with commonly used metallic and nonmetallic materials;
- nonflammability or relative low flammability;
- nontoxicity or low toxicity;
- low impact on health—no inhalation, skin, and eye problems;
- nonozone depleting;
- environmentally safe; and
- disposable.

Follow SDS precautions and use required personal protective equipment (PPE). Used cleaning agents shall be disposed of in accordance with applicable national and local regulations.

Cloths used for wiping components or equipment surfaces shall be clean, lint-free, and free from traces of oil or grease. Cotton, linen, or paper are commonly used materials. Cleaning cloths should not have fluorescent dyes, brighteners, or other additives that could transfer to the surface of the components giving false indication that the surface is fluorescing.

4.3.1 Cleaning agents

Typical cleaning agents include abrasives, aqueous and semi-aqueous/emulsion solutions, and solvents. Abrasives remove scale, rust, varnish, paint, slag, and excess weld material. Aqueous or semi-aqueous/emulsion cleaning agents remove dirt, loose scale, oxides, rust, oils, fluxes, and other contaminants. Solvents remove hydrocarbon oils, greases, cutting fluids, and silicone greases.

Select the type of cleaning agent to match the contaminants to be removed.

The effectiveness of cleaning agents is strongly influenced by:

- type of contaminants to be removed;
- configuration and complexity of equipment to be cleaned:
 - size of component/equipment to be cleaned (small, large)
 - form of component/equipment to be cleaned (simple, complex with dead ends or crevices)
 - surface to be cleaned (condition, texture, material);
- where cleaning is carried out (workshop, field);
- when cleaning is carried out (during manufacture, installation or construction, maintenance);
- state of the equipment to be cleaned (assembled, disassembled); and
- cleaning method used, including parameters such as temperature and concentration of the cleaning agents, and if mechanical energy is applied (such as scrubbing, agitation, and ultrasonic energy).

In some cases, a cleaning agent test may be run prior to choosing the cleaning agent.

Ultrasonic agitation may be used to enhance the loosening of oil and grease or other contaminants from the component surface using high frequency vibrational energy. Ultrasonic agitation is typically used in conjunction with immersion cleaning. The cleaning effectiveness is strongly dependent on the shape, the quantity, and the positioning of the components in the bath. An alternating current generates ultrasonic vibrations that give rise to cavitation in the liquid. When the cavitation voids implode, mechanical cleaning energy in the form of small jets

is created. The cleaning fluid in the immersion bath shall be free from gas bubbles as these can absorb the ultrasonic energy. Consideration shall be given to the energy absorption properties of porous, ceramic, or soft components as these properties can impact the effectiveness of ultrasonic agitation. Under specific conditions, brittle materials can be damaged by ultrasonic agitation.

4.3.1.1 Aqueous and semi-aqueous/emulsion cleaning

Aqueous and semi-aqueous/emulsion cleaning agents dissolve water soluble contaminants and remove water insoluble contaminants by dispersing and emulsifying them. Thorough rinsing is required when using aqueous and semi-aqueous/emulsion cleaning agents to carry the contamination and cleaning agent residues off the component surface. The use of aqueous and semi-aqueous/emulsion cleaning agents generally requires heat, sufficient contact time, and mechanical energy for cleaning.

4.3.1.1.1 Aqueous cleaning

Aqueous cleaning solutions are water based with or without alkaline, acid, and/or detergent cleaning agents. Immersion, forced circulation, and spray equipment are used for aqueous cleaning. Aqueous cleaning effectiveness can be improved by adding mechanical energy. Immersion equipment frequently uses agitation to aid in contamination removal. Ultrasonic agitation can remove tightly bound contaminants in complex components. Spray equipment cleans parts by applying the cleaning solution at medium to high pressure. Cleaning solutions are prepared with low foaming surfactants and additives. Aqueous systems can be optimized for a specific contaminant or set of contaminants. Aqueous cleaning solutions can require heating to achieve the desired results. Prolonged heating of the cleaning solution can be necessary when the temperature of the component(s) is less than the temperature required for the cleaning solution. Challenges in aqueous cleaning include difficulties in rinsing to remove cleaning agent residues and drying cleaned components. Some metals or polymers can be incompatible with aqueous solutions. See 6.2 for information on selecting an appropriate aqueous cleaning agent and process.

Cleaning solutions can require wastewater treatment prior to disposal depending upon solution additives or the contaminants removed [5].

Aqueous cleaning agent residues are often corrosive as well as incompatible with oxygen and therefore pose a potential hazard. Thorough rinsing with water is mandatory to ensure that all residual cleaning agent residue, surfactants, etc. are removed from the component or system.

The supplier of the cleaning agent should be consulted for specific use conditions and procedures including rinse operations.

4.3.1.1.2 Semi-aqueous/emulsion cleaning

Semi-aqueous/emulsion cleaning processes apply solvent/surfactant emulsions in concentrated form followed by a water rinse, or emulsions in water are used in processes similar to aqueous cleaning. Semi-aqueous/emulsion cleaning processes are effective in removing heavy grease, tar, waxes, and other hydrocarbon contaminants. Cleaning solutions can be made compatible with most metals and polymers, and metals are not likely to be etched since the solutions are neutral. Semi-aqueous/emulsion cleaning solutions can require heating to achieve the desired results. Prolonged heating of the cleaning solution can be necessary when the temperature of the component(s) is less than the temperature required for the cleaning solution. Emulsification of the hydrocarbons reduces evaporative losses and volatile organic compounds (VOC) emissions. Rinsing and drying can be difficult using this process. Wastewater treatment is usually required because of the dissolved organics (emulsions). Flammability of the hydrocarbon solvent is a concern with concentrated cleaners; some have objectionable odors, and some are VOCs [5]. See 6.4 for information on selecting an appropriate semi-aqueous/emulsion cleaning agent and process.

Semi-aqueous/emulsion cleaning agent residues are often corrosive as well as incompatible with oxygen and therefore pose a potential hazard. Thorough rinsing with water is mandatory to ensure that all residual cleaning agent residue, surfactants, etc., are removed from the component or system.

The supplier of the cleaning agent should be consulted for specific use conditions and procedures including rinse operations.

4.3.1.2 Solvent cleaning

The selection of a solvent depends on many factors including material compatibility, environmental impact, health effects (for example, toxicity, carcinogenicity), performance characteristics, flammability, ease of use, and availability. Solvents shall be tested for material compatibility, particularly if the equipment to be cleaned has nonmetallic components. Environmental issues include ozone depletion potential, contribution to global warming, and the potential to produce smog due to VOCs. The use of many solvents is regulated and shall be in accordance with applicable national and local regulations and standards. Many used or spent solvents and some unused solvents being disposed of are classified as hazardous waste and/or are subject to annual emissions reporting requirements under Title III of the *Superfund Amendments and Reauthorization Act* [5].

The solvent's flash point should be considered in the selection of the solvent and the cleaning method. Flammable solvents (low flash points) should only be used in immersion cleaning equipment designed to handle such solvents. Spray, immersion, and forced circulation cleaning equipment can be used for nonflammable (high flash point) solvents that also minimize emissions. For immersion cleaning, ultrasonic agitation may be used to enhance the loosening of oil and grease or other contamination from the component surface using high frequency vibrational energy. A solvent's toxicity and carcinogenicity shall be considered and its recommended threshold limit values shall be adhered to. Low boiling point and low heat of vaporization enhance the drying process and minimize the chance of thermal damage to the parts being cleaned. However, low vapor pressure solvents are slow to evaporate and therefore could remain after assembly, possibly leading to an explosion hazard upon subsequent exposure to oxygen. Low surface tension and low viscosity allow a solvent to penetrate into blind holes, crevices, porous surfaces, and over complex geometries [5].

The production of many of the solvents traditionally used to clean for oxygen service is being phased out (see 4.3.2.1). However, many new solvents are being developed specifically for cleaning and are becoming commercially available. These include terpene-, aliphatic hydrocarbon-, alcohol-, ester-, hydrochloro-fluorocarbon-, hydrofluorocarbon-, and silicone-based solvents. Due to their greater volatility, solvents may be more appropriate for equipment configurations such as valves, heat exchangers, compressors, etc. with crevices, intricate passages, and/or inaccessible areas where visual/instrumental inspection and removal of cleaning agents is restricted. If a solvent is used, select one with a low level of nonvolatile residue. Because solvents and their residues can be incompatible with oxygen, ensure that all of the cleaning agent has been drained from the system and all remaining traces are thoroughly evaporated to dryness before the introduction of any oxygen-enriched fluids. See 6.3 for selecting an appropriate solvent and cleaning method.

4.3.2 Environmental considerations

4.3.2.1 Emissions to air

In 1987, an international agreement was reached in Montreal, Canada, that called for a reduction in the production of atmospheric ozone depleting substances (ODS). The *Montreal Protocol on Substances that Deplete the Ozone Layer* and resulting government regulations restrict the use of many solvents and prohibit their release to the atmosphere [6]. Most of these substances are being phased out worldwide. A widely used oxygen cleaning solvent, 1,1,1-trichloroethane, is among the substances that has been phased out and shall not be used. Alternative cleaning solvents that meet the regulations are available.

VOCs are a major source of photochemical smog and ground level ozone that have harmful effects on human health and the environment. ODSs can also impact human health and the environment.

Emissions to air from cleaning operations such as VOCs, ODSs, etc., shall comply with applicable national and local regulations (U.S. Environmental Protection Agency *Clean Air Act* (CAA), European Union Regulations, etc.).

4.3.2.2 Discharge to surface water and groundwater

Contamination of surface water and groundwater can arise from improper waste disposal, inadequate effluent water treatment, or accidental spillage caused by improper handling or storage in the case of solvents. Discharges to surface water and ground water shall comply with applicable national and local regulations.

4.3.2.3 Handling of used cleaning agents

Used cleaning agents shall be stored and disposed of in accordance with the applicable national and local regulations and the manufacturer's recommendations.

4.3.3 Cleaning methods

The cleaning method used, which includes removal of the cleaning agent, depends on several factors:

- desired level of cleanliness;
- type of contaminants;
- location and degree of contamination;
- arrangement of equipment and piping with respect to the ability to be flushed and drained;
- speed and effectiveness of the cleaning agent in removing the contaminants;
- compatibility of the cleaning agent with the contaminants, metals, and nonmetallic components involved;
- availability and cost of cleaning agents and cleaning methods;
- availability of personnel experienced in handling these materials; and
- local environmental and disposal considerations.

Typical cleaning methods include:

- mechanical cleaning:
 - blast cleaning
 - wire brushing
 - tumbling;
- aqueous cleaning:
 - steam or hot water cleaning
 - alkaline cleaning
 - acid cleaning
 - detergent cleaning;
- solvent cleaning; and
- semi-aqueous/emulsion cleaning.

The user should prepare a detailed cleaning procedure that considers the guidelines provided by the cleaning agent manufacturer. See Appendix A.

4.3.4 American Society for Testing and Materials references

The American Society for Testing and Materials (ASTM) has prepared four guides designed to aid in the selection of cleaning agents:

- [ASTM G93](#), *Standard Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments*, covers the selection of methods and apparatus for cleaning materials and equipment intended for service in oxygen-enriched environments [3];

- [ASTM G121](#), *Standard Practice for Preparation of Contaminated Test Coupons for the Evaluation of Cleaning Agents* [7] provides a consistent method for evaluating the cleaning effectiveness of potential oxygen cleaning agents;
- [ASTM G122](#), *Standard Test Method for Evaluating the Effectiveness of Cleaning Agents* also provides a consistent method for evaluating the cleaning effectiveness of potential oxygen cleaning agents [8]; and
- [ASTM G127](#), *Standard Guide for the Selection of Cleaning Agents for Oxygen-Enriched Systems* establishes a procedure for an oxygen producer, user, or component or system manufacturer to use in working with cleaning agent suppliers in selecting agents suitable for their applications [9].

5 Precleaning

Before cleaning, component materials incompatible with the cleaning agents shall be removed or isolated. Gross amounts of foreign materials such as scale, dirt, grit, solid objects, and hydrocarbons should be removed to improve effectiveness of subsequent cleaning methods. Removal can be accomplished by one or more of the mechanical cleaning methods described in 6.1.

6 Cleaning

6.1 Mechanical cleaning

A risk assessment shall be carried out considering the hazards associated with mechanical cleaning, the nature of the application, the risks to health of those involved in the cleaning process, and the experience of the personnel in order to define appropriate control measures including waste disposal.

Mechanical cleaning is usually a preparatory step in the cleaning process. The process of mechanical cleaning often consists of two phases. The first phase is the loosening of particles, which can be accomplished by chipping, scraping, blast cleaning, wire brushing, grinding, or tumbling, as described in 6.1.1, 6.1.2, and 6.1.3.

The second phase consists of removing the debris generated in the first phase by vacuuming or high velocity blow out using dry oil-free compressed air or nitrogen or a combination of these as described in 6.1.4.

Some mechanical cleaning methods such as blast cleaning can achieve the desired final cleanliness level in a single step (not just a preparatory step). Contaminants that cannot be eliminated by such methods (for example, markings carried out with some marking pens) shall be noted and removed by another process.

Mechanical cleaning is not recommended for nonmetallic materials or for accurately dimensioned components as the method can cause uneven material loss.

Selection of the mechanical cleaning method will depend upon several factors:

- extent of contamination;
- ability of the method to remove the contaminants;
- equipment or component to be cleaned, its shape, and the ability to remove all cleaning debris and cleaning materials;
- effect of the cleaning materials/method on the materials of the equipment or component to be cleaned; and
- surface finish required for the equipment or component.

NOTE—For additional information on surface finish after mechanical cleaning, see 1) Standard N9, Rugotest No. 3, ISO 2632-1, *Roughness comparison specimens—Part 1: Turned, ground, bored, milled, shaped and planed* and ISO 2632-2, *Roughness comparison specimens—Part 2: Spark-eroded, shot-blasted and grit blasted, and polished* [10, 11]. Alternatives are Sa 2 ½ ISO 8501-1, *Preparation of steel substrates before application of paints and related products. Visual assessment of surface cleanliness. Representative photographic examples of the change of appearance imparted to steel when blast-cleaned with different abrasives* Spec BSA2 and [ASTM G93](#) Section 10 [12, 3].

6.1.1 Blast cleaning

Blast cleaning is the use of abrasives propelled against the surface of pipe, components, or equipment to be cleaned to remove mill scale, rust, varnish, paint, or other foreign matter. The materials and medium propelling the abrasive shall be oil-free unless the oil is to be removed by subsequent cleaning. The specific abrasive materials used shall be suitable for cleaning without depositing contaminants that cannot be removed by subsequent cleaning. Care shall be taken not to remove an excessive amount of parent metal that could compromise the mechanical integrity and required finish of the component. This method should not be used on aluminum alloy, copper, nickel, and other soft metal alloys due to the possibility of uneven metal loss and embedding of grit.

The blasting medium and residue shall be removed to meet the cleanliness levels required for oxygen service equipment. It is recommended that blast cleaning materials be used on a once through basis. However, if the material is re-used, it shall not redeposit any contaminants back onto the component or equipment being cleaned.

Materials that can be used for blast cleaning include:

- copper slag particles;
- water ice as pellets;
- carbon dioxide as dry ice pellets;
- glass beads in high pressure water or dry air; and
- sand.

Metallic shot (powder or grains of cast iron, iron, steel, etc.), walnut shells, carbide grit, and oxide grit can also be used. However, these materials shall be used only if their complete removal can be ensured as these materials can burn or initiate ignitions when the system is put in oxygen service.

NOTE—Blasting media may be subject to regulatory restrictions due to their hazardous properties (for example, crystalline silica).

6.1.2 Wire brushing, grinding, and chipping

Wire brushing, grinding, and chipping are cleaning methods that use handheld tools. Accessible surfaces can be wire brushed. Welds can be ground and wire brushed to remove slag, grit, or excess weld material. Wire brushes manufactured from stainless steel, copper, brass, or bronze wires are recommended. Carbon steel wire brushes shall not be used. Any wire brushes previously used on carbon steel shall not be used on stainless steel, aluminum, copper, nickel, or other soft metal alloy surfaces. Wire brushing can be used with alkaline solutions to enhance cleaning.

Mechanical tube cleaners may also be used. These are flexible shaft driven rotating wheel assemblies that carry out a chipping action inside the tubes to remove mill scale, fouling, etc.

6.1.3 Tumbling

Tumbling is a cleaning method that uses a hard abrasive material placed in a container to clean the component. The container is rotated to impart relative motion between the abrasive material and the component. This method is useful for cleaning small parts and fittings.

6.1.4 Final mechanical cleaning steps

After the equipment and components have been mechanically cleaned, equipment and component surfaces shall be:

- vacuumed to remove loose particles and debris; or
- blown out with dry, oil-free air or an inert gas to remove remaining particles.

NOTE—Refer to [CGA G-4.4, Oxygen Pipeline and Piping Systems](#) for additional information on achieving effective blowout of piping systems [13].

After vacuuming or blowing, the equipment and components may be swabbed or wiped with a suitable cleaning solvent using a clean, lint-free cloth to remove loose particles.

6.2 Aqueous cleaning

A risk assessment shall be carried out considering the hazardous properties of the aqueous cleaning agent, the nature of the application, the risks to health of those involved in the cleaning process, and the experience of the personnel in order to define appropriate control measures including waste disposal.

Aqueous cleaning methods commonly employ immersion cleaning, forced circulation, spraying, and wiping.

For immersion cleaning and forced circulation, any cleaning solution can be reused until it becomes ineffective as determined by pH or contaminant concentration analysis. Experience developed using inspection techniques helps to establish a contaminant level of the cleaning solution above which a surface cannot be acceptably cleaned.

Immersion cleaning

Individual components can be cleaned by immersing the component in aqueous solution at ambient or elevated temperatures and by applying a means of agitation. Where possible, disassemble components prior to cleaning by this method. Cleaning effectiveness can be improved by the use of ultrasonic agitation, which aids in the loosening of oil and grease or other contamination from metal surfaces through high frequency vibrational energy.

A test for contamination should be run periodically on the aqueous solution used for immersion cleaning of components.

Forced circulation

Components may be cleaned by forced circulation of the aqueous solution through the components at ambient or elevated temperature. The aqueous solution should be tested periodically. If the solution is found to be contaminated beyond acceptable levels, it shall be drained from the equipment and replaced with a batch of clean solution. Cleaning should continue until the used aqueous solution is comparable in cleanliness to the reference sample.

Forced circulation is applied principally to equipment that cannot be disassembled such as large systems, pre-fabricated circuits, and piping. The use of this method is limited by the ability of the aqueous solution to reach contaminants present in all areas of the system as well as the subsequent complete removal of the circulated solution.

6.2.1 Steam or hot water cleaning

The steam or hot water cleaning method can be carried out using commercially available equipment for cleaning of components, equipment, and pipes. It removes oil, grease, dirt, and loose scale as well as welding and brazing residues and other contaminants. The addition of detergents can improve the performance of this cleaning method.

The cleaning medium is steam or heated water that is jet sprayed onto the component or equipment at a high pressure). If high volume flushing is required, only heated water is used. The high temperature and pressure enhance the removal of contaminants. Wastewater and steam condensate shall be disposed of in accordance with applicable national and local regulations.

Ensure that the component or equipment to be cleaned will not be damaged due to high temperature and pressure of the water or steam jet. Care should be taken to avoid ingress of moisture into electrical equipment on or adjacent to the component or equipment being cleaned.

6.2.1.1 Materials

The steam or hot water shall be clean and oil-free. In most steam or hot water cleaning operations, a detergent solution is combined with the steam or hot water to provide an acceptable level of final cleanliness. The detergents selected shall be suitable for the contaminants involved and also shall be compatible with the surfaces being cleaned.

6.2.1.2 Equipment

6.2.1.2.1 Steam cleaning

Typical steam cleaning equipment consists of a steam and water supply, length of hose, and steam lance with or without a spray nozzle.

6.2.1.2.2 Hot water

Typical cleaning with hot water uses a spray system or an immersion tank with suitable agitation of either the solution or the parts to be cleaned.

6.2.1.3 Cleaning methods

6.2.1.3.1 Steam

Either plant steam or steam from a portable steam generator can be used. If a steam lance is used, the detergent solution can enter the steam gun by venturi action and mix with the steam. Steam removes oils, greases, and soaps by first thinning them at elevated temperatures. Dispersion and emulsification of the oils then occur, followed by dilution with the condensed steam. The system should provide control over the steam, water, and detergent flows so the full effects of the detergent's chemical action, heat of the steam, and abrasive action of the pressure jet are combined for maximum cleaning effectiveness.

If the steam is clean and free of organic material, a secondary cleaning operation with a solvent or alkaline degreaser may not be required in cases where the initial contamination is removed to an acceptable level with steam.

6.2.1.3.2 Hot water

Hot water cleaning removes gross organic and particulate contamination from parts by using low to moderate heat. Using detergent and mechanical agitation can improve this cleaning process. Consideration shall be given to the size, shape, and number of components to be cleaned to ensure adequate contact between the surfaces to be cleaned and the solution. The solution temperature should follow the cleaning agent manufacturer's recommendation. Mechanical energy can be applied in the form of ultrasonic or mechanical agitation to achieve acceptable results. Soaking helps to soften foreign material but does not remove it without scrubbing or agitation. A dishwasher can be effective in some applications.

6.2.1.4 Removal of cleaning agent

If a detergent is used, ensure that the cleaning process is followed by a rinsing step using water. See 7.1.

All water shall be drained from the system and thoroughly dried before introduction of oxygen-enriched fluids. See 7.2.

6.2.2 Alkaline cleaning

Alkaline cleaning is cleaning with solutions of high alkalinity for the removal of heavy oil or grease or tenacious surface contamination followed by a rinsing operation.

NOTE—Alkaline cleaning solutions can cause crevice corrosion.

6.2.2.1 Materials

Many effective cleaning agent materials are available for alkaline cleaning. They are alkalis that are water soluble and nonflammable and can be harmful if they come in contact with the skin or eyes or if they are swallowed. The cleaning agents shall be chosen so they do not react chemically with the materials being cleaned. See Table 1.

The following alkaline chemicals, often as aqueous solutions, are used:

- sodium hydroxide (NaOH) caustic soda;
- sodium carbonate (Na₂CO₃), soda ash, or sodium bicarbonate (NaHCO₃) (buffer solution);
- sodium phosphates (for example, Na₃PO₄, Na₂HPO₄) (water softener, emulsifier, and buffer); and
- sodium silicates (for example, Na₂SiO₃) (emulsifiers and buffers).

Additives for water softening, corrosion inhibition, and wetting may be necessary to address water quality and effectiveness of cleaning.

Table 1—Alkaline chemical cleaning agents (also applicable to alkaline detergents)

Metal	Contaminants	Cleaning agents
Carbon, low alloy steels, and 9% nickel steel	Heavy soil, grease, and oil	Mixtures of sodium hydroxide, sodium carbonates, sodium phosphates, sodium silicates, and synthetic wetting agents
Austenitic stainless steel, ferritic stainless, nickel-based alloys, duplex stainless steel	Heavy soil, grease, light oils, and cutting fluids	Mixtures of sodium hydroxide, sodium carbonates, sodium phosphates, sodium silicates, and synthetic wetting agents
Copper and copper alloys	Greases, lubricating oils, drawing/extruding compounds, oxides, metallic particles, etc.	Mixtures of sodium hydroxide, sodium polyphosphates, sodium silicates, sodium carbonates, and synthetic wetting agents
	Brazing fluxes	Hot water
Aluminum and aluminum alloys ^{1), 2)}	Greases, oils, and oxides	Etching—mixtures of sodium hydroxide and sodium phosphate Nonetching—Mixtures of sodium carbonate, sodium silicate, sodium pyrophosphate, and sodium metasilicate Dilute nitric acid dip to remove deposits remaining after alkali cleaning
NOTES ¹⁾ Risk of production of hydrogen gas. ²⁾ Alkali and acid cleaners are detrimental to aluminum and most aluminum alloys. The use of such cleaners on aluminum and its alloys may compromise the mechanical properties of the materials [14].		

The manufacturer's specification for application of the cleaning agent shall be followed. After using alkaline chemicals, all components shall be thoroughly rinsed using flowing water, preferably hot to aid drying, unless otherwise prohibited by the cleaning agent supplier. There is a risk of stress corrosion cracking (SCC) unless all cleaning agents are thoroughly removed. For information on health and safety precautions for alkaline cleaning, see 13.4.3.

6.2.2.2 Equipment

Cleaning equipment typically consists of a storage or immersion tank, recirculation pump, and associated piping and valving compatible with the alkaline solution.

6.2.2.3 Cleaning methods

The cleaning solution can be applied by spraying, immersion, forced circulation, or wiping.

Spraying works well but requires a method where the cleaning solution reaches all areas of the surface. It is also desirable to have provisions for draining the solution faster than it is introduced to avoid accumulation.

When immersion and forced circulation are used, the surfaces to be cleaned shall be continuously wetted since the solution tends to dry on any surface exposed to air. Wiped surfaces should be rinsed before the cleaning solution dries.

Generally, cleaning solutions perform better when warm. Depending upon the particular solution, this temperature can be in the range of 100 °F to 180 °F (37.8 °C to 82.2 °C).

6.2.2.4 Removal of cleaning agent

Ensure that the cleaning process is followed by a rinsing step using water. See 7.1.

All water shall be drained from the system and thoroughly dried before introduction of oxygen-enriched fluids. See 7.2.

6.2.3 Acid cleaning

Acid cleaning uses low pH solutions to remove oxides and other contaminants.

NOTE—Acid cleaning solutions can cause crevice corrosion in assemblies.

6.2.3.1 Materials

Acid cleaning materials and their suitability are summarized in Table 2.

For information on health and safety precautions for acid cleaning, see 13.4.3.

In most cases, the type of cleaning agent selected depends on the material to be cleaned. The following general guidelines can be used:

- Phosphoric acid-based cleaning agents can be used for all metals. These agents remove light rust, light oils, fluxes, and protective coatings such as chrome rich spinel on stainless steel and iron oxide on steel;
- Hydrochloric acid-based cleaning agents are recommended only for carbon and low alloy steels. These agents remove rust, scale, and oxide coatings and can also strip chromium, zinc, and cadmium platings. An inhibitor should be used in certain acid solutions such as hydrochloric or nitric acids to prevent harmful attacks on base metals due to the solubility of metal oxides in these acid solutions. Hydrochloric acid shall not be used on stainless steel since it can cause SCC;
- Nitric acid-based cleaning agents are recommended for aluminum and aluminum alloys. These agents are not true cleaning agents but are used for deoxidizing, brightening, and for removing black smut, which forms during cleaning with an alkaline solution. For copper and copper alloys, nitric acid-based cleaning solutions are recommended only for brightening. Some agents are available as liquids and others as powders and are mixed to concentrations of 5% to 50% in water depending on the cleaning agent and the amount of oxide or scale to be removed. Nitric acid solutions can react with copper and copper alloys producing toxic fumes. Adequate ventilation is necessary; and
- Following chemical pickling of carbon and low alloy steel surfaces, passivation using phosphoric acid, sodium nitrite, or phosphate treatment is necessary to prevent flash rusting. See 6.2.3.3.

Acid-based cleaning agents should not be used unless their application and performance are known or are discussed with the cleaning agent manufacturer. The manufacturer's specification (duration of use, temperature, and concentration of solution) for application of these acid-based cleaning agents shall be followed to prevent impairment of the metal (such as hydrogen embrittlement) and for safe handling and use of the cleaning agent. Acid solutions that attack the base metal or react with contained moisture may require the addition of inhibitors.

There are commercially available products and solutions designed either for descaling and/or for corrosion protection. The exact compositions of these products are not always provided so they shall not be used unless the suitability of these solutions has been verified.

Table 2—Acid chemical cleaning agents

Metal	Contaminants	Cleaning/passivating chemicals ^{1), 2), 3)}
Carbon and low alloy steels	Scale/oxide films	Inhibited hydrochloric or sulfuric acid and wetting agents (for pickling) ⁴⁾
	Light rust	Citric, sulfuric, or phosphoric acid
	Grease, oil, or drawing compound	Phosphoric acid and synthetic detergents mixture
Cast iron	Oxides	Chromic acid; or Mixture of sulfuric and hydrofluoric acid
Austenitic stainless steel	Tarnish, scale/oxides, and inorganic deposits	Mixture of chromic, sulfuric, and hydrofluoric acid; Mixture of nitric, hydrofluoric, and phosphoric acids; Mixture of nitric and hydrofluoric acid; or Sulfuric acid followed by mixture of nitric and hydrofluoric acid
Copper and copper alloys	Scale/oxides	Hydrochloric or sulfuric acid (for pickling) ⁴⁾
Aluminum and aluminum alloys ⁴⁾	Oxides	Mixture of chromic and sulfuric acid; Mixture of nitric and hydrofluoric acid; or Mixture of phosphoric and chromic acid

NOTES

¹⁾ 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.

²⁾ A variety of mineral acids or solutions of acid salts, often used in conjunction with inhibitors, surfactants (wetting agents), and solvents can be used for cleaning and/or passivating metal surfaces. Factors critical to the cleaning/passivation effectiveness with minimum attack on the metal, and user safety include: a) correct composition of the acid solution intended for cleaning or passivating; (b) application process including mechanical action, time and temperature; (c) post cleaning/passivation steps which may include a neutralization or water rinse step [15]. Note that acid cleaning is primarily used for scale removal and oxide removal (or formation) and is not very effective for removing hydrocarbon compounds unless combined with solvents or detergents (surfactants). The purpose of passivation is to generate a material less likely to degrade in a particular application, and specific passivation conditions are governed by standards (for example, for stainless steels [ASTM A380](#), *Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems*; [ASTM A967](#), *Standard Specifications for Chemical Passivation Treatments for Stainless Steel Parts*, and [AMS 2700E](#), *Passivation of Corrosion Resistant Steels*) [16, 17, 18].

³⁾ Post chemical 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.

⁴⁾ Risk of production of hydrogen gas.

6.2.3.2 Equipment

Cleaning equipment typically consists of a storage or immersion tank, recirculation pump, and associated piping and valving compatible with the acid solution.

6.2.3.3 Cleaning methods

Common methods of applying acid cleaning agents used for cleaning metals include:

- Forced circulation with an appropriate acid solution for large systems, prefabricated circuits, and piping; and
- Immersion in the solution with scrubbing or agitation for small parts.