CLEANING OF EQUIPMENT FOR OXYGEN SERVICE

Doc 33/18

Revision of Doc 33/06

EUROPEAN INDUSTRIAL GASES ASSOCIATION AISBL

AVENUE DES ARTS 3-5 • B – 1210 BRUSSELS
Tel: +32 2 217 70 98 • Fax: +32 2 219 85 14
E-mail: info@eiga.eu • Internet: www.eiga.eu

Doc 33/18

CLEANING OF EQUIPMENT FOR OXYGEN SERVICE

As part of the programme of harmonisation of industry standards, the European Industrial Gases Association, (EIGA) has published EIGA Doc 33, *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.

The publication was developed from the Compressed Gas Association Publication, G-4.1 *Cleaning Equipment for Oxygen Service* and the EIGA Document, Doc 33 *Cleaning of Equipment for Oxygen Service*.

.

Disclaimer

All technical publications of EIGA or under EIGA's name, including Codes of practice, Safety procedures and any other technical information contained in such publications were obtained from sources believed to be reliable and are based on technical information and experience currently available from members of EIGA and others at the date of their issuance.

While EIGA recommends reference to or use of its publications by its members, such reference to or use of EIGA's publications by its members or third parties are purely voluntary and not binding.

Therefore, EIGA or its members make no guarantee of the results and assume no liability or responsibility in connection with the reference to or use of information or suggestions contained in EIGA's publications.

EIGA has no control whatsoever as regards, performance or non performance, misinterpretation, proper or improper use of any information or suggestions contained in EIGA's publications by any person or entity (including EIGA members) and EIGA expressly disclaims any liability in connection thereto.

EIGA's publications are subject to periodic review and users are cautioned to obtain the latest edition.

© – Reproduced with permission from the Compressed Gas Association. All rights reserved.

EUROPEAN INDUSTRIAL GASES ASSOCIATION AISBL
Avenue des Arts 3-5   B 1210 Brussels   Tel +32 2 217 70 98   Fax +32 2 219 85 14
E-mail: info@eiga.eu   Internet: www.eiga.eu

Oxygen Cleaning : sales@varakana.com   www.varakana.com

Table of Contents

Amendments to 33/18

Section	Change
	Editorial to align style with IHC associations
	Complete rewrite following technical review

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) aluminium 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, fibre, 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.

---

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

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.

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 Fibre

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, fibres, powder, and uncontaminated by oil or grease are allowed. Items contaminated when used for other services such as automotive maintenance or fuelling 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 analysed 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;
- non-corrosivity;
- compatibility with commonly used metallic and non-metallic materials;
- nonflammability or relative low flammability;
- nontoxicity or low toxicity;
- low impact on health – no inhalation, skin, and eye problems;
- non-ozone 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 odours, 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 non-metallic 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 non-flammable (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, hydrochlorofluorocarbon, 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 non-volatile 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 on VOCs and other solvents.).

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 non-metallic 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 non-metallic 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 aluminium 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, aluminium, 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 EIGA Doc 13, *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, prefabricated 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 non-flammable 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 (Na_2CO_3), soda ash, or sodium bicarbonate ($NaHCO_3$) (buffer solution);
- sodium phosphates (for example, Na_3PO_4, Na_2HPO_4) (water softener, emulsifier, and buffer); and
- sodium silicates (for example, Na_2SiO_3) (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
Aluminium and aluminium alloys 1), 2)	Greases, oils, and oxides	Etching: mixtures of sodium hydroxide and sodium phosphate Non-etching: 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 aluminium and most aluminium alloys. The use of such cleaners on aluminium 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 37.8 °C to 82.2 °C (100 °F to 180 °F).

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 aluminium and aluminium 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)
Aluminium and aluminium 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.

If required, acid passivation of steel components is performed after components have been degreased using solvent or alkaline treatments. Cleaning solutions should not be allowed to dry on the component. Cleaning solutions shall be thoroughly rinsed away before passivation.

Chemical pickling using acid solutions is applied to ferrous alloys to remove impurities such as rust, scale, and certain protective coatings. The operation shall be completed by rinsing with a neutralizing product or with water until the rinsing water outlet pH is ± 0.2 of the initial water pH. Chemical passivation is a treatment used to provide short-term corrosion protection of carbon and low alloy steel surfaces, which have been pickled. Phosphoric acid (H_3PO_4) or sodium nitrite solutions are used for this treatment. After treatment, the component shall be completely rinsed and dried. Surfaces treated in this way have a uniform grey colour, occasionally with some highlights of a reddish-brown colour due to salt deposits from the passivation products.

Any black deposits left on the surface, which can be slightly sticky to touch, are an indication that passivation is inadequate, and that treatment should be repeated to the extent necessary.

6.2.3.4 Removal of cleaning agent

Components shall be thoroughly rinsed using water as soon as practicable after cleaning to prevent excessive attack on the material being cleaned by the acid cleaning solution. See 7.1. Following this rinse step, if there is a chance of any cleaning solution becoming trapped in the equipment being cleaned, a dilute alkaline neutralizing solution can be applied, followed by another water rinsing.

Surfaces appearing to have white powder indicate inadequate rinsing; therefore, repeat the rinsing until satisfactory results are achieved.

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

6.2.4 Detergent cleaning

Detergent cleaning is performed using water solutions containing chemicals that have different functions such as dirt removal, dispersion, water softening, corrosion inhibition, and wetting. It is normally performed in an alkaline environment; a higher pH value results in better degreasing efficiency.

6.2.4.1 Materials

Commercially available detergents are supplied as a solid or as a concentrated liquid. They are mixed with hot water to form aqueous solutions that can be pumped, recirculated, or sprayed onto or through the component. They are well suited as cleaning agents in ultrasonic baths. Important detergent components are the surfactants that decrease the surface tension of the aqueous solution and penetrate and disperse the organic contaminants into small droplets. It is also important to ensure that the detergents used have a high rinsability and leave minimal residues. Common components in detergents and their main function are summarized in Table 3.

The degreasing capability of aqueous solutions is similar to that of solvents. Advantages of aqueous cleaning solutions include lower flammability and explosivity, and lower toxicity for most formulations as compared to solvents. Used solutions and wastewater shall be disposed of in accordance with applicable national and local regulations.

Ensure that the detergents used are compatible with non-metallic materials. Some non-metallic materials are not compatible with these detergents or can absorb the cleaning solution.

Table 3—Common components in alkaline detergents and their main function

Examples of common components	Main function
Sodium hydroxide Potassium hydroxide Sodium carbonate Sodium silicate	Dirt removers pH raising agents
Sodium silicate Polyphosphates Other surfactants (tensides)	Dispersants
Polyphosphates Borates Glyconates	Softeners
Sodium silicate Borates Amines	Corrosion inhibitors
Polyphosphates Glyconates	Wetting agents

Other surfactants (tensides)	

6.2.4.2 Equipment

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

6.2.4.3 Cleaning methods

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

Follow the detergent manufacturer’s instructions regarding solution concentration, compatibility of materials, and safety precautions required.

For components with narrow cavities, immersion cleaning should be used, where all parts of the contaminated components come in contact with the cleaning agent. Spray cleaning should not be used for these components.

Detergent solutions have higher surface tension compared to organic solvents and therefore have difficulty penetrating into narrow cavities. Cleaning effectiveness can be improved by circulation, scrubbing, agitation, or ultrasonic energy;

Rotation of the component could be necessary to eliminate air pockets.

Increased temperature of the detergent solution improves cleaning effectiveness. The solution should be heated to manufacturer’s recommended temperature.

6.2.4.4 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.

6.3 Solvent cleaning

Solvent cleaning is a method for the removal of organic contaminations from the surface to be cleaned.

6.3.1 Materials

A risk assessment shall be carried out considering the hazardous properties of the solvent, 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.

Solvents shall be tested for material compatibility, particularly with any non-metallic components in the equipment to be cleaned. ASTM G127 can be used to aid in the selection of an appropriate solvent and cleaning process [9].

Solvents used for oxygen cleaning include acetone, isopropyl alcohol, and many other commercially available solvents.

Solvents used shall be of stabilized grade of proven suitability. Unstabilized solvents can cause metal corrosion. The presence of moisture can accelerate the corrosive effects and, therefore it is essential that care is taken to maintain the quality of the solvents in use.

6.3.1.1 Control of solvent cleanliness

6.3.1.1.1 Reference sample

Before a new batch of solvent is used for any cleaning operation, a sample of the solvent should be withdrawn for reference purposes. This sample should be stored in a clean container made of materials that will not contaminate the sample.

6.3.1.1.2 Checking solvent suitability for re-use

After a period of use, the suitability of the solvent for re-use may be determined in one of several ways:

- Colour comparison with the reference sample — In the colour comparison, it is assumed that the solvent is still sufficiently clean to use if it shows no distinct colour change from the reference sample. The colour change can be determined visually or by instrument, comparing the simultaneous light transmission through both samples. This should be verified by analytical tests to detect probable contaminants or by calculation of the amount of residue deposited by evaporation of contaminated solvent;

    - Analytical test — Although more time consuming, analytical techniques (for example, infrared spectroscopy or chromatography) can precisely measure the extent of solvent contamination with a known contaminant, for example, a particular cutting oil used to machine parts. However, if one or several unknown contaminants are present, results can be more difficult to interpret; or

    - Evaporation tests — Contamination can be checked by calculation of the amount of residue deposited by evaporation of contaminated solvent (see 8.1.5). Evaporation of a solvent and measurement of the residue depend on the nonvolatility of any contaminants. However, the vapor pressures of most oils are sufficiently high that significant amounts could evaporate with a large volume of solvent. Therefore, an evaporation determination can give only a lower limit to the amount of dissolved contaminant.

Re-use of the solvent also requires consideration of the cleaning method and degree of contamination of the component being cleaned. Contaminated solvents that are not suitable to achieve the desired cleanliness may be re-used as is for initial cleaning, reclaimed by appropriate procedures, or disposed of in accordance with applicable national or local regulations.

6.3.2 Equipment

Solvent cleaning equipment typically consists of a recirculating system for the solvent or an open or closed container for immersing parts (depending on the solvent).

For ultrasonic cleaning, a high-frequency sound generator and container are substituted for the recirculation system.

CAUTION: *Some solvents can extract the plasticizer of some plastic tubing including polyvinylchloride (PVC) and polymethylmethacrylate (PMMA) and deposit it on the surface being cleaned. Rubber, neoprene, and nylon components can be degraded by the solvent and deposit on the surface being cleaned. Ensure that any non-metallic components are compatible with the solvent being used. Consult the solvent manufacturer's literature or contact them directly for information on compatible plastics. Polytetrafluoroethylene (PTFE) components are satisfactory for use with chlorinated solvents.*

6.3.3 Cleaning methods

Almost all solvents and their residues are flammable in oxygen and precautions shall be taken to completely remove the solvents and residues. Detailed procedures for purging and inspection shall be developed to ensure that at the end of purging, the solvent or its residue do not remain in the component, equipment, or system.

An assessment of the component or system to be cleaned shall be made to ensure that there are no dead ends or pockets present from which it will be difficult to completely drain and dry out the solvent. If the solvent cannot be completely removed, then solvent cleaning shall not be used unless the system can be modified to accommodate this method.

Components of a simple shape with all surfaces accessible can be cleaned by wiping with a solvent using a clean, lint-free cloth followed by drying. Other solvent cleaning methods used are described in the following sub sections:

- immersion cleaning;
- forced circulation; and
- vapour degreasing.

6.3.3.1 Immersion cleaning

Individual components can be cleaned by immersing the component in solvent at ambient temperatures and 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 solvent used for immersion cleaning of components. If the solvent is contaminated beyond acceptable levels, it shall be replaced with a batch of clean solvent.

Immersion solvent cleaning can require subsequent rinsing with clean solvent.

6.3.3.2 Forced circulation

Components may be cleaned by forced circulation of the solvent through the components at ambient temperatures. The solvent 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 solvent. Cleaning should continue until the used solvent is comparable in cleanliness to the reference sample.

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

6.3.3.3 Vapour degreasing

Vapour degreasing is a method for the removal of soluble organic materials from the surfaces of the component or equipment by the continuous condensation of solvent vapours and their subsequent washing action.

The vapor degreasing method is useful for cleaning when the temperature of the equipment or component being cleaned is between the freezing and boiling points of the solvent so that the solvent vapours condense on the component surfaces and wash down the contaminants by gravity. The condensation of the vapor and cleaning action stops when the temperature of the component or equipment reaches the boiling point of the solvent.

This cleaning method requires that the solvent be boiled in a vaporizer and the solvent vapours then contact a cooler component on whose surface the vapours condense and carry away the soluble contaminants.

There are two methods:

- In the first method, cleaning action occurs by placing components inside a vapor degreaser chamber into which the solvent vapor rises from a vaporizer chamber. The solvent vapor condenses on the exposed surfaces of the component and washes the contaminants. The components shall be positioned to allow condensed solvent to drain back to the vaporizer; or

- In the second method, hot solvent vapor can be piped from a vaporizer into the vessel where it condenses on the inner surfaces and cleaning occurs. The vessel being cleaned shall be positioned and connected so that all of the condensate drains back to the solvent vaporizer.

Continuous removal of the condensate and its transport back into the vaporizer carries the dissolved impurities into the vaporizer, where they remain while fresh pure vapours are released to continue the degreasing operation.

Cleaning can be considered complete when the returning condensate is as clean as the reference sample.

A description of the method for one type of equipment is given in Appendix B.

6.3.4 Removal of cleaning agent

After cleaning, crevices and dead zones can still contain solvent. It is vital that all of the solvent be removed from all dead spaces since an explosion can result upon subsequent contact with oxygen. After the oil and grease contaminants have been removed and the solvent drained, remove any remaining solvent by purging with dry, oil-free air or nitrogen. Continue purging until the final traces of the solvent have been removed.

Comparative evaporation rates (butyl acetate=1.0) are available from manufacturers. The ability of a solvent to evaporate quickly helps to complete the purging step faster. The properties of the solvent shall be considered when determining if heating of the purge gas is required to remove the remaining solvent.

Purging is complete when the solvent cannot be detected in the purge gas exiting from the component being purged. Solvents may be detected by odour testing, photo ionization detector (PID) testing, or other methods. Odour testing shall not be used for solvents that are toxic. If odour testing is used, see 4.3.1.2 and 8.1.6. For odourless solvents, a detector/PID tester suitable for the solvent can be used.

6.4 Semi-aqueous/emulsion cleaning

Semi-aqueous/emulsion cleaning uses solvent-water emulsions to remove heavy contaminants such as oil and grease from the component surfaces with organic solvents dispersed in an aqueous medium by an emulsifying agent. This method does not apply to the removal of oxides.

6.4.1 Materials

A risk assessment shall be carried out considering the hazardous properties of the semi-aqueous/emulsion 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.

Emulsion cleaners have three main components: water, an organic solvent, and surfactants.

In an emulsion, a solvent is emulsified in water by surface-active agents. The cleaning is accomplished by the solvent droplets that combine with the contaminants and are then removed by water rinsing. The cleaning efficiency can be increased by adding alkaline agents and surfactants (tensides). The cleaning action of the emulsion combines the advantages of both detergent and solvent cleaning.

An alternative cleaning method using water-free solvents with emulsifiers functions similar to solvent cleaning. The emulsification of the solvent and contaminants only takes place when water is added in the subsequent rinsing step.

For safety and environmental reasons, solvents with a high flash point and a low vapor pressure are normally chosen. Suitable solvents include high boiling point hydrocarbons, citrus-based terpenes (for example, d-limonene), pine-based terpenes, esters (for example, lactate esters), and glycol ethers. When using emulsifiers, comply with the manufacturer’s recommendations.

The impact on the environment from emulsion cleaners originates from vaporized solvent. However, vaporization of solvent is less compared to pure solvent cleaning because of the lower solvent concentration in the emulsion and the lower solvent vapour pressure.

6.4.2 Equipment and cleaning methods

Emulsions are used for cleaning the same type of components as water-based detergent cleaners. The methods and equipment used are also similar to detergent cleaning. Immersion cleaning, forced circulation, spraying, and wiping are commonly used cleaning methods. See 6.2 for information on immersion cleaning and forced circulation.

Ensure that emulsifiers used are compatible with all metallic and non-metallic materials.

The concentration of dissolved contaminants in the cleaning solution can be considerably higher for emulsions compared to aqueous solutions before the cleaning effect diminishes. The penetration into narrow cavities is more effective compared to pure aqueous cleaning solutions.

6.4.3 Removal of cleaning agent

The cleaning shall be followed by thorough rinsing with water to remove the cleaning agent and to prevent contaminants from redepositing on the surface. See 7.1

Cleaned parts shall be dried after rinsing. See 7.2

7 Rinsing and drying

7.1 Rinsing

Aqueous and semi-aqueous/emulsion cleaning methods involving alkaline, acid, and/or detergent cleaning agents require subsequent rinsing with water to remove remaining cleaning agents and residues. The cleanliness attained is only as good as the rinsing. Many cleaning agents remaining in an oxygen system are a severe hazard and shall be removed by rinsing. It is essential that any residual cleaning agent (in hidden areas, crevices, or porous surfaces) be completely removed. Some of the contaminants can be held in suspension in the cleaning solution. However, if the cleaning solution is not completely flushed from the surface being cleaned, the contaminants in any remaining solution redeposit on the surface during the drying operation. Rinsing shall be performed immediately after cleaning. The surface shall not be allowed to dry between the cleaning phase and the rinsing phase. If this happens, it is very likely that the film or residue that forms will not be adequately removed during the rinsing phase.

Rinsing water will frequently leave water spots after rinsing and drying. These are the results of the hardness of the water and are typically harmless in contact with oxygen.

The rinsing operation can take place in one or more steps by immersion, forced circulation, and/or spraying. In immersion rinsing baths, some type of agitation such as mechanical brushing, fluid impingement, or agitation of the parts being cleaned, could be necessary. Ultrasonic energy may also be used to improve the rinsing efficiency. Spray rinsing should be used only for components where all surfaces can be directly contacted by the sprayed liquid.

The rinsing water is often warmed to help remove the cleaning solution and aid in the drying process. Alkaline cleaning agents can be more difficult to rinse and may require higher rinsing temperatures.

For alkaline and acid cleaning methods, monitoring the pH of the outlet rinse water should be used to determine the completion of the rinsing step. The rinsing should be continued until the rinsing water outlet pH is ±0.2 of the initial water pH.

7.2 Drying

Aqueous and semi-aqueous/emulsion cleaning methods require that the cleaned and rinsed components are thoroughly dried. Prior to the start of drying, ensure that rinse water is drained as much as possible. Porous components and components with small or narrow cavities are difficult to dry. Quickly drying components can help to minimize corrosion. Typically, a dew point of at least –22 °F (–30 °C) is considered to be dry.

In selection of a drying process, consideration shall be given to the level of dryness required. Each method should be evaluated for the specific application intended. Commonly used drying methods include:

- physical—actual removal of liquid such as wiping, centrifuging, or blowing; and
- evaporation—adding energy and physically removing moisture through methods such as drying by oven or purge.

Small- and medium-sized components are often dried in gas-purged ovens. System and vessel drying can be achieved by purging with flowing, ambient temperature dry, oil-free air or nitrogen. However, this can take a considerable amount of time to achieve the desired dryness close to the dew point of the drying gas. Drying can be accelerated either with hot gas or radiation heating. When selecting the heating temperature, consideration shall be given to the potential to damage the equipment and components being dried, in particular non-metallic materials and aluminium alloys. When visual confirmation for dryness is not possible, the completion of the drying process can be determined by periodically measuring the venting gas dew point.

8 Inspection

8.1 Inspection methods

After the completion of cleaning, inspection shall be performed to verify cleanliness. Various inspection methods exist for determining the cleanliness of the cleaned component. A combination of methods could be necessary to assess the cleanliness of a component.

Inspection methods include:

- direct visual inspection with white light;
- direct visual inspection with ultraviolet (UV) light;
- wipe test;
- water break/ink test;
- solvent extraction test;
- odour test; and
- chromatographic, spectrometric, and other detection methods.

Other inspection methods may be used as agreed to by specifier/user and cleaning service provider.

Parts that are inaccessible for inspection after assembly require inspection prior to assembly or disassembly for inspection.

If an inspection reveals the presence of unacceptable levels of contamination, the component shall be recleaned. Persistent rejection requires a re-evaluation of the cleaning methods used.

8.1.1 Direct visual inspection with white light

This is the most common method used to detect the presence of contamination such as oils, greases, preservatives, moisture, corrosion products, weld slag, scale, filings, chips, and other foreign matter. The equipment or component is observed without magnification under bright white light for the absence of contaminants. This method detects particulate matter greater than 50 μ (0.002 in) and moisture, oils, greases, etc. in relatively large amounts (for example, more than 500 mg/m^2 of hydrocarbon oils on stainless steel).

Visual inspection under bright white light shall show no evidence of:

- organic material such as oil, grease, paint, crayon, etc.;
- cleaning agents and their residues;
- particles such as rust and loose scale, weld spatters, dust, lint and other fibres, or other foreign matter;
- flux residues from welding, brazing, or soldering; and
- moisture.

The equipment or component being examined shall be recleaned if any visible contamination is detected by this inspection method. A slight discoloration resulting from a light film of oxide is acceptable for carbon steel piping.

8.1.2 Direct visual inspection with ultraviolet light

Ultraviolet (UV) light, commonly known as black light, causes some oils, greases, detergent residues, and lint and other fibres to fluoresce. Since not all contaminants fluoresce, UV light inspection alone cannot be relied upon as a test for cleanliness. This method shall only be used after performing direct visual inspection using white light and not observing any contamination.

The surface is observed in darkness or subdued lighting using a UV light radiating at wavelengths between 2500 angstrom to 4000 angstrom units. The UV light inspection lamp shall be of intensity greater than 800 $\mu W/cm^2$ at the surface being inspected (typically requiring a minimum of 50 W power for mercury halogen lamps). Prior to cleaning a component or part, the part should be inspected to see if the contamination present is, in fact, fluorescent under UV light prior to the cleaning process. This makes post inspection with UV light to validate the effectiveness of the cleaning procedure more substantive. Increasing the distance between the UV lamp and the surface being inspected reduces the light intensity and the ability to detect contamination.

Some UV lights (particularly mercury halogen) age over time and there is a reduction of light intensity. These underpowered UV lights should not be used unless tested to show that they can detect fluorescent oils under control conditions. Control conditions should be comparable to those contamination levels that are required to be detected during inspection.

CAUTION: *Excessive exposure to direct or reflected UV light can cause eye and skin damage. Care shall be taken when using UV light and users shall comply with lamp manufacturer’s instructions.*

Visual inspection under UV light shall show no fluorescence of:

- hydrocarbons;
- cleaning agents and their residues; and
- particles such as lint and other fibres or other foreign matter. Some materials such as cotton lint that fluoresce are acceptable unless present in excessive amounts. See 9.1

The equipment or component being examined shall be recleaned if any visible contamination is detected by this inspection method.

8.1.3 Wipe test

This test is used to detect contaminants on visually inaccessible areas as an aid in the previous direct visual inspections. The surface is rubbed lightly with a clean, white, paper or lint-free non-fluorescing cloth that is then visually examined under white light. If no contamination is seen, examine using UV light. The area should not be rubbed hard enough to remove any oxide film since this could be confused with any actual surface contamination. The equipment or component being examined shall be recleaned if an unacceptable amount of contamination is detected by this inspection method.

8.1.4 Water break/Ink test

These tests are based on the surface tension of a liquid on an oily surface and are sensitive for detecting low contamination levels.

For the water break test, the surface is wetted with a spray of water that should form a thin layer and remain unbroken for at least 5 seconds. Beading of the water droplets indicates the presence of oil contaminants and that recleaning is required.

In principle, the ink test is similar to the water break test. Due to the use of different ink qualities, different quantitative contaminant levels of the sample can be detected. The test is relatively easy and delivers good quantitative information about the level of oil contamination. It is done by drawing an ink line on the surface. If the line breaks into different sections after a few seconds, the oil contamination is greater than the limit mentioned on the ink bottle (for example, 50 mg/m²). If the ink stays in one continuous line, then contamination is less than this level. See Figure 1.

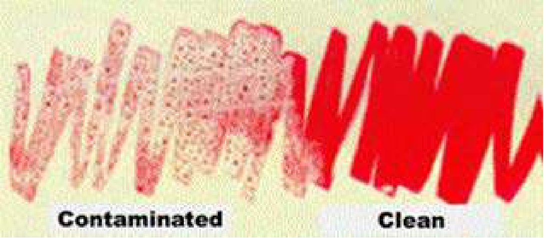

Figure 1—Example of water break/ink test results

The pen test is a modification of the ink test. Instead of using different ink solutions, a set of pens with different inks are used. The test is relatively easy and provides good quantitative information about the level of oil contamination. The advantage is that the pen can also be used on small round surfaces like small valve bodies. It is done by drawing a line on the surface. If the line edges stay sharp after a few seconds, the oil contamination is less than the limit mentioned on the pen (for example, 50 mg/m²). If the edges expand, then it is greater than this level.

These methods are generally limited to horizontal and smooth metal surfaces. This test is not applicable to most water-soluble lubricants and other water-soluble contaminants. If water soluble lubricants are known to be present, check to see if this test works on a control test specimen, typically a thin, near invisible deposit of the oil on a metal coupon or other flat, smooth, horizontal surface.

Any surface that has been tested with ink and pens shall be free of ink residues prior to use in oxygen service.

8.1.5 Solvent extraction test

This method can be used to supplement visual techniques or to perform cleanliness tests for specific hydrocarbon contaminations. This method is suitable to check inaccessible surfaces by using a solvent to extract contaminants for inspection. The surface is flushed, rinsed, or immersed in a low-residue solvent. Solvent extraction is limited by the ability of the solvent to reach and dissolve the contaminants present and by the loss of contaminants during solvent evaporation (see 6.3.1.1.2). The equipment tested also typically contains materials such as polymers or elastomers that would be attacked by the solvent and give erroneous results.

The used solvent can be checked to determine the amount of non-volatile residue by one of the following methods: weight of residue or light transmission.

8.1.5.1 Weight of residue

A known quantity of a representative sample of unfiltered used solvent is contained in a small weighed beaker and is evaporated to dryness being careful not to overheat the residue and the weight (m_2) of the residue established. In the same manner, the weight (m_1) of residue from a similar quantity of clean solvent is determined. The difference in weight between the two residues and the quantity of representative sample used is related to the total quantity (m_v) of solvent used and can be taken to compute the amount of residual contaminant removed per square meter (m_c) of surface area (A) cleaned.

$$m_c = \frac{(m_2 - m_1)m_v/m_s}{A}$$

Where:

m_1 = weight of residue (clean solvent)

m_2 = weight of residue (used solvent)

m_s = weight of representative sample (used solvent)

m_v = total weight of solvent used

A = surface area of component cleaned

m_c = weight of contamination present per area cleaned

8.1.5.2 Light transmission

The light transmission through a known quantity of the used solvent is simultaneously compared to a similar sample of new solvent. There should be little, if any, difference in colour of the solvents and very few particles. Sufficient path length should be incorporated when making colour or clarity comparisons. A standard Nessler tube provides a sufficient path length for comparing light transmission of used solvent to virgin solvent.

8.1.6 Odour test

Although an odour test is not generally required, it is required for applications such as medical and food gas systems. This test is intended to make sure that cleaning agent or residue is not present in the cleaned component or system. When the test is performed, if the odour of a solvent is detected then the component or system shall be re-purged with oil-free air or nitrogen until no odour is detected. If the odour of an aqueous cleaning agent is detected, then the component or system shall be rinsed with water until no odour is detected. The component or system shall then be thoroughly dried using oil-free air or nitrogen. If the odour persists, the component shall be recleaned. If nitrogen is used for purging, all safety precautions shall be taken to prevent asphyxiation.

Instead of odour testing, PID testing may be used. For odourless solvents, a detector/PID tester suitable for the solvent shall be used.

8.1.7 Spectrometric, chromatographic, and other detection methods

These detection methods are only used in certain applications. Small amounts of oil or grease contamination can be detected and measured by these methods. The measuring instruments used for these detection methods are complex and require specific operating instructions.

9 Contamination level

9.1 Acceptable contamination levels

The acceptable contamination level of non-volatile contaminants shall be less than 220 mg/m^2 (20 mg/ft^2) [19]. Factors such as oxygen purity, pressure, temperature, and application can affect the acceptable contaminant level. A risk assessment shall be conducted if a higher contaminant limit is used.

Contamination levels less than 220 mg/ m^2 (20 mg/ft^2) are required for aluminium alloy structured packing used for oxygen distillation (see EIGA Doc 144, *Safe Use of Aluminium-Structured Packing for Oxygen Distillation* [20].

The acceptable contamination level for particles should be no more than 22 particles/m^2 (2 particles/ft^2) between 500 μ and 1000 μ. No particle shall be larger than 1000 μ. The total particles shall not exceed

110 mg/m^2 (10 mg/ft^2) or 825 particles/m^2 (75 particles/ft^2). Isolated fibres of lint shall be no longer than 2000 μ, and there shall be no accumulation of lint fibres [3].

These acceptable levels can be demonstrated from a representative surface area of the equipment.

9.2 Contaminant detection thresholds for non-volatile contaminants

Minimum detection level of an inspection method depends on the type of contaminant and the material contaminated, which is the reason for the wide range provided in Table 4. These ranges are provided for information only and do not apply to all types of contaminants. See ASTM STP 910, *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Second Volume* for more information on these ranges [21].

Table 4—Minimum detection levels for hydrocarbon oil contaminants on stainless steel [21]

Inspection method	Contaminant detection threshold (mg/m^2)
Bright white light	500 – 1700
UV light	40 – 1500
Wipe test	30 – 600
Water break test	30 – 60
Solvent extraction	<10

A combination of test methods results in a lower threshold of detection.

10 Packaging and maintaining cleanliness

Once a component or equipment has been cleaned and inspected, it shall either be used immediately or packaged and labelled to prevent recontamination during storage, transportation, and prior to installation and commissioning. The packing shall be carried out in a clean area.

Once they have passed inspection, care shall be taken to ensure that cleaned components or equipment are not re-contaminated during assembly or packaging. Tools used for assembly or installation shall be cleaned to prevent them from contaminating the component and equipment. If there is any question regarding cleanliness, inspection of the component or equipment is required and, if necessary, recleaning is carried out.

Components or equipment that are not immediately used after cleaning and inspection shall be packaged using new, clean plastic bags or other appropriate means:

- Plastic sheeting may be used on components as necessary in place of separate bags;
- Openings on large components shall be sealed with caps, plugs, or blind flanges. Taped solid board blanks or other durable covers that cannot introduce contamination to the equipment can also be used to seal such openings;
- Small valves, parts, gaskets, and fittings shall be packed or bagged in plastic bags and sealed for protection from contamination. Individual packing may be considered depending on intended application.
- Equipment with large internal volumes may be filled to a slight positive pressure with dry, oil-free air or nitrogen after all openings have been sealed. A label or tag shall be attached, designating the pressurizing gas and internal pressure. If purged with nitrogen, the potential asphyxiation hazard shall be noted on the label;
- Protective coverings shall not leave a residue. Do not use any adhesives on surfaces that could be exposed to oxygen. The adhesive in waterproof cloth (duct tape) is not oxygen compatible and is difficult to remove; and
- All protective caps, plugs, blinds, and other packaging shall be kept in place until final assembly or installation.

Components or equipment in damaged or opened packages or having illegible labels shall be re-inspected and, if necessary, recleaned.

Oxygen service cleaned components such as valves, piping, and fittings shall be stored in areas designated for oxygen service cleaned components or equipment. These shall be segregated from components and equipment that have not been cleaned for oxygen service.

Prior to installation, accessible parts of equipment or components shall be visually inspected to ensure cleanliness has been maintained. If contamination is suspected, the equipment or component shall be recleaned to meet the original cleanliness specification.

10.1 Desiccant bags

Desiccant bags are sometimes placed inside equipment or packaging to reduce humidity during shipment or storage.

The following may be used:

- alumina;
- silica gel;
- molecular sieve; and
- regenerated clays.

Certain colour additives may be present in the desiccants to give an indication of the moisture content. If possible, desiccant bags shall be connected in groups so that they can be removed together. When removing the bags, care shall be taken to ensure that they are intact and that all are removed.

10.2 Pressure testing

When any pressure test is carried out on equipment after completion of the cleaning operation, it is essential to maintain the oxygen clean conditions. For hydraulic testing, water shall be used. After testing, the component or equipment shall be drained and dried and purged with oil-free, dry air or nitrogen. For pneumatic testing, oil-free, dry air or nitrogen shall be used.

11 Labelling

All components and equipment cleaned for oxygen service shall have a label indicating CLEANED FOR OXYGEN SERVICE. The number of desiccant bags, if any, that have been put inside the equipment or packaging shall be indicated on the label. As a minimum, a label shall be visible from outside the package. Adhesive labels are not to be applied directly to surfaces that could be exposed to oxygen.

Additional information that may be included is:

- a statement, “This equipment is cleaned in accordance with Oxygen Cleaning Specification No. ________”;
- date of inspection and the inspector’s stamp or marking;
- description of the part, including part number and serial number if available;
- statement, “Do not open until ready to use”; and
- warning of asphyxiation hazard, if applicable, indicating pressurizing gas and internal pressure.

12 Quality assurance, quality control measures for oxygen cleaning

Quality control needs to be a joint effort between the specifier/requester and provider of the cleaning service, whether an original equipment manufacturer (OEM) or a third-party cleaning service provider. The required quality can only be achieved if a common understanding of what needs to be done is established.

To achieve this, the oxygen service cleaning provider and personnel shall be qualified through an audit process to demonstrate their capability to perform oxygen service cleaning including:

- Oxygen cleaning procedure and cleaning agent for suitability for the service intended. Ensure that the oxygen service cleaning provider understands and follows procedure requirements;
- Reference list indicating experience with oxygen service cleaning;
- Validation of effective and operable quality management system(s) capable of meeting specifier/requester oxygen service cleaning specifications and requirements;
- Resource management/human resources—training/competencies for oxygen service cleaning;
- Capture of lessons learned from quality control non-compliances;
- Ensuring that the specified cleanliness level(s) and acceptance criteria can be met (qualification of the cleaning method, cleanliness verification process, cleaning room/area organization). See Appendix A;
- Packaging procedures and preservation, labelling and marking;
- Standard documentation (inspection documentation, cleanliness certificate). See 12.1; and
- Periodic re-auditing shall be conducted by the specifier/requester to maintain the provider qualification.

The specifier/requester shall be notified prior to implementing any changes to the oxygen cleaning procedure approved by the specifier/requester (for example, change of the cleaning agent, work process, inspection methodology, etc.).

12.1 Record keeping

Records shall be prepared for the cleaned component or equipment, kept on file, and, if requested, a copy forwarded to the specifier/requester. Records may include the following:

- descriptive name of the component or equipment covered;
- serial or drawing number;
- invoice number or other means of identification;
- cleaning specification and method employed;
- dates of inspection for cleanliness;
- method of inspection;
- results of inspection; and
- inspector’s signature and date.

13 Personnel safety

Cleaning operations for oxygen service equipment shall be carried out in a manner that provides for the safety and health of personnel performing the work and shall conform to applicable national and local regulations.

Efforts should be made to use environmentally friendly and nontoxic cleaning agents. However, the use of highly toxic, carcinogenic, potentially carcinogenic, mutagenic, or reprotoxic cleaning agents could be required to adequately clean some components and equipment. Consult the SDS for complete information on the hazards of any cleaning agents. In no case shall carbon tetrachloride, trichloroethane, and trichlorofluoroethane be employed in any cleaning operation.

Persons performing cleaning shall be instructed in the safe use of the cleaning agents including any hazards associated with these agents. Appropriate procedures shall be put in place to ensure the safe use, handling, and disposal of these cleaning agents.

The health hazards associated with the use of any solvent shall be considered in its selection. The user shall ensure that the Threshold Limit Value–Time-Weighted Average (TLV®–TWA) is not exceeded for a specific solvent [22]. Breathing of solvent fumes and liquid contact with the skin should be avoided. SDSs for solvents should be obtained from the solvent manufacturer.

Caution shall be exercised in using solvents commonly referred to as non-flammable that are flammable in air under certain conditions. The concentrations creating a flammable mixture in air are usually well in excess of the concentration that cause physiological harm. Therefore, when removing solvents to the extent necessary to protect personnel from respiratory harm, it shall not be forgotten that purging with air can create a flammable mixture. Also, failure to purge adequately can leave a flammable mixture that in the presence of heat, flame, or sparks can result in a dangerous energy release.

Follow industry practices and manufacturer's recommendations when mixing and handling acids and alkalines to eliminate injuries.

13.1 Personal protective equipment

PPE is necessary to protect from hazards associated with cleaning agents. For information on the selection of PPE, see EIGA Doc 136, *Selection of Personal Protective Equipment* [23].

Self-contained breathing apparatus (SCBA) or supplied breathing air shall be used wherever there is a possibility of a deficiency of oxygen due to the use of an inert gas purge. Respiratory protection may be required if there is any possibility of exceeding allowable TLVs of cleaning agents (see EN 140 *Respiratory protective devices. Half masks and quarter masks. Requirements, testing,* marking) [24].

13.2 Ventilation

All areas where cleaning agents are used shall be adequately ventilated. In outdoor operations, locate cleaning operations so that operators can work upwind of solvent vapor accumulations.

13.3 Specific situations

13.3.1 Entering confined space

Work shall not be performed inside a vessel or other confined space until the vessel or confined space has been prepared and work procedures are established that ensure the safety of workers. Potential hazards of vessel entry include asphyxiation and flammability and toxicity of chemicals. See UK Health and Safety Executive *Safe work in confined spaces* for guidance on confined space entry [25].

13.3.2 Heating solvents

Upon heating, some solvents can break down into dangerous compounds, some at temperatures not much greater than the boiling point of water. Review the SDS for solvents being used to determine if this hazard exists.

Ventilation shall be adequate to prevent breathing excessive amounts of the solvent vapours or their decomposition products. Air respirators shall be used in situations where the concentration of solvent vapours or any other foreign material in the atmosphere exceeds the TLV.

13.3.3 Welding near solvents

Parts to be welded shall be free of cleaning solvents. UV rays and heat from welding can decompose certain solvents to produce hazardous gases. Accordingly, the atmosphere in the vicinity of such operations shall be free from those solvent vapours.

Review the SDS for solvents being used to determine if this hazard exists.

13.4 Health and safety considerations

13.4.1 Mechanical cleaning precautions

Mechanical cleaning creates dust and other particulates resulting from the breakdown of the materials used and also by the removal of surface material from the component or equipment being cleaned. The particulate, if breathed, can be hazardous to health (for example, quartz dust) and can also cause serious damage when coming in contact with the eyes. Safety precautions shall be taken to address these hazards.

13.4.2 Steam or hot water cleaning precautions

- Suitable protective clothing, gloves, apron, face shield, and goggles shall be worn while carrying out steam or hot water cleaning operations; and
- Follow the equipment supplier’s instructions for the use and handling of the cleaning lances. Both hands shall always be on the spray lance.

13.4.3 Acid and alkaline cleaning precautions

- Chemical cleaning agents shall only be used when their suitability, performance, and safety requirements are fully understood. Comply with the manufacturer’s recommendations;
- Suitable protective clothing, gloves, apron, face shield, and goggles shall be worn while carrying out chemical cleaning operations;
- Avoid eye and skin contact with acid and alkaline cleaning agents as burns or serious skin disorders can result;
- Avoid breathing of fumes caused by the reaction of the chemicals with the metals being cleaned;
- When performing acid cleaning in enclosed vessels, precautions need to be taken due to the formation of flammable hydrogen gas and potentially toxic fumes resulting from contact of acids with the metal surfaces;
- Acids shall always be slowly added to water when preparing cleaning solutions. Never add water to concentrated acids as it results in an exothermic reaction and can cause splashing of the acid due to boiling;
- Acids and alkalis shall never be disposed of directly into the drainage system. Used cleaning solutions shall be disposed of in accordance with applicable national and local regulations and the manufacturer’s recommendations; and
- Use appropriate procedures when neutralizing acid or alkaline solutions. Never add acid to an alkaline solution or alkaline to an acid solution with the intent of neutralizing the solution. There is a possibility that a chemical reaction between the acid and the alkaline solution will take place and generate a hazardous chemical such as chlorine.

13.4.4 Detergent cleaning precautions

- Detergent cleaning agents shall only be used when their suitability, performance, and safety requirements are fully understood. Comply with the manufacturer's recommendations;
- Suitable protective clothing, gloves, apron, face shield, and goggles shall be worn while carrying out detergent cleaning operations; and
- Avoid eye and skin contact with detergent chemicals as injuries or skin disorders can result.

13.4.5 Solvent cleaning precautions

- Solvent cleaning agents shall only be used when their suitability, performance, and safety requirements are fully understood. Comply with the manufacturer's recommendations;

- Suitable protective clothing, gloves, apron, face shield, and goggles shall be worn while carrying out solvent cleaning operations;
- Avoid eye and skin contact with solvents;
- Solvent toxicity and carcinogenicity shall be considered. Do not exceed the recommended TLV. Follow SDS precautions;
- Vapours from some solvents are a powerful anaesthetic. When inhaled in small quantities, they can cause drowsiness. In large quantities, vapours can cause unconsciousness and can be fatal. Adequate ventilation shall be provided in areas used for solvent cleaning. To avoid exposure greater than permitted levels, solvents shall not be purged from components in confined spaces. For outdoor solvent cleaning operations, it is recommended that people are positioned upwind of the solvent handling location;
- Emissions to the atmosphere shall be kept to a minimum and in accordance with national and local regulations;
- Containers of solvent shall not be left in working areas without lids or caps fitted and shall be suitably labelled;
- Some halogenated solvents can decompose to form toxic gases (for example, phosgene) in the presence of heat sources or UV radiation. Avoid exposure of these solvents to daylight over a prolonged period;
- Open flames and welding shall be prohibited where solvent vapours are present. Solvents shall not be heated to greater than the allowable temperature. This temperature shall be determined in consultation with the solvent supplier or from other relevant information such as the SDS. Heating of solvents shall always be by indirect methods;
- Most solvent vapours are capable of creating an explosive mixture at certain concentrations with air or oxygen. It is important to ensure that parts to be welded or heated are totally free of solvent;
- Solvents shall only be carried using suitable containers; and
- Aluminium and aluminium alloys without the protective oxide film react vigorously with halogenated solvents to produce acid vapor that is both toxic and corrosive. This occurs particularly on particles of aluminium alloys such as swarf or particles from machining or cutting processes. When using solvents to clean aluminium, the following should be observed:
  - Use only clean solvent that contains the correct level of inhibitors for cleaning aluminium or its alloys
  - Cleaning should not be performed immediately after machining aluminium alloy components. Sufficient time with exposure to ambient air should be allowed in order to create the protective oxide film prior to degreasing
  - Ensure that the aluminium and aluminium alloy component or equipment being cleaned is free from particles and swarf
  - Components should be placed gently into the degreasing tank to avoid damaging the protective oxide film and
  - Solvents shall not be kept in contact with aluminium and its alloys for extended periods. After cleaning, remove solvents as quickly as possible from the component or equipment.

13.4.6 Semi-aqueous/emulsion cleaning precautions

- Semi-aqueous/emulsion cleaning agents shall only be used when their suitability, performance, and safety requirements are fully understood. Comply with the manufacturer's recommendations;

- When using emulsions, risks of the solvents and other chemical components involved shall be considered. See also 13.4.5, solvent cleaning precautions and 13.4.4, detergent cleaning precautions;
- Inhalation is the primary safety concern;
- Avoid skin and eye contact with emulsion chemicals as skin damage and injuries can result. Personnel carrying out emulsion cleaning shall wear goggles and a face mask with appropriate filter depending on the composition of the emulsion and on the operating conditions during cleaning; and
- Emulsions are considered non-flammable in bulk form but can be flammable in aspirated or mist conditions. The cleaning equipment should be designed to minimize the risk of flammable mists.

14 Training

Personnel shall be trained on the specific task(s) that they are performing such as:

- cleaning including solvent/solution handling;
- cleanliness inspection;
- assembly and disassembly of parts;
- packaging and labelling;
- record keeping requirements; and
- used cleaning agent/solution disposal.

Training shall also address potential hazards of the cleaning agents and methods.

Periodic retraining is recommended to ensure that the personnel skill level remains current. Satisfactory completion of training/retraining shall be documented.

15 References

Unless otherwise specified, the latest edition shall apply.

[1] *Code of Federal Regulations,* Title 49 (Transportation) Parts 100-188, U.S. Government Printing Office. www.gpo.gov

[2] ISO 8573-1 *Compressed air -- Part 1: Contaminants and purity classe*s., www.iso.org

[3] ASTM G93, *Standard Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments*, ASTM International. www.astm.org

[4] EIGA Doc. 44 Hazards of inert gases and oxygen depletion. www.eiga.eu

[5] Walter, A.E. and J.W. Parker, “Solvent-Based Cleaning: A Viable Alternative for Precision Cleaning,” *Precision Cleaning*, February 1994, Clean*Tech*. www.cleantechcentral.com

[6] *Montreal Protocol on Substances that Deplete the Ozone Layer,* United Nations Environment Programme, Ozone Secretariat. www.unep.org/ozone

[7] ASTM G121, *Standard Practice for Preparation of Contaminated Test Coupons for the Evaluation of Cleaning Agents,* ASTM International. www.astm.org

[8] ASTM G122, *Standard Test Method for Evaluating the Effectiveness of Cleaning Agents,* ASTM International. www.astm.org

[9] ASTM G127, *Standard Guide for the Selection of Cleaning Agents for Oxygen-Enriched Systems*, ASTM International. www.astm.org

[10] ISO 2632-1, *Roughness comparison specimens—Part 1: Turned, ground bored, milled, shaped and planed.* American National Standards Institute. www.iso.org

[11] ISO 2632-2, *Roughness comparison specimens—Part 2: Spark-eroded, shot-blasted and grit blasted, and polished.* American National Standards Institute. www.iso.org

[12] 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*. American National Standards Institute. www.iso.org

[13] EIGA Doc 13, *Oxygen Pipeline and Piping Systems*, Compressed Gas Association, Inc. www.eiga.eu

NOTE—This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

[14] ASTM MNL 36, *Safe Use of Oxygen and Oxygen Systems: Handbook for Design, Operation, and Maintenance.* ASTM International. www.astm.org

[15] Metals Handbook (ASM Handbook): Volume 5. Surface Cleaning, Finishing, and Coating. ASM International. www.asminternational.org

[16] ASTM A380, *Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems,* ASTM International. www.astm.org

[17] ASTM A967, *Standard Specifications for Chemical Passivation Treatments for Stainless Steel Parts*, ASTM International. www.astm.org

[18] AMS 2700E, *Passivation of Corrosion Resistant Steels*, SAE International. www.sae.org

[19] ASTM STP 812, *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres*, ASTM International. www.astm.org

[20] EIGA Doc 144, *Safe Use of Aluminium-Structured Packing for Oxygen Distillation*, Compressed Gas Association, Inc. www.eiga.eu

NOTE—This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

[21] ASTM STP 910, *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres*: *Second Volume*. ASTM International. www.astm.org

[22] *TLVs® and BEIs® Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, American Conference of Governmental Industrial Hygienists. www.acgih.org

[23] EIGA Doc 136, *Selection of Personal Protective Equipment*, Compressed Gas Association, Inc. www.eiga.eu

NOTE—This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

[24] EN 140 *Respiratory protective devices. Half masks and quarter masks. Requirements, testing, marking* www.cen.eu

[25] UK Health and Safety Executive *Safe work in confined spaces* www.hse.gov.uk

16 Additional references

EIGA Doc 145, *Safe Use of Brazed Aluminium Heat Exchangers for Producing Pressurized Oxygen*, Compressed Gas Association, Inc. www.cganet.com

NOTE—This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

EIGA Doc 147, *Safe Practices Guide for Cryogenic Air Separation Plants*, Compressed Gas Association, Inc. www.cganet.com

EIGA Doc 65, *Safe Operation of Reboilers/Condensers in Air Separation Units*, Compressed Gas Association, Inc. www.cganet.com

NOTE—This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

EN 12300 *Cryogenic Vessels—Cleanliness for Cryogenic Service*, European Committee for Standardization. www.cen.eu

ISO 23208, *Cryogenic vessels—Cleanliness for cryogenic service,* American National Standards Institute. www.cen.eu

Appendix A — Cleaning procedure (Informative)

A1 Purpose of a cleaning procedure

The cleaning procedure is a detailed documented description of all individual steps for the components and equipment to be cleaned. Important elements are:

- parameters considered;
- preparation of components and systems to be cleaned;
- description of the cleaning method;
- description of the cleanliness inspection;
- handling of nonconformities;
- maintaining cleanliness;
- labelling and documentation;
- validation of cleaning method.

Work flow and responsibilities of involved staff should be addressed in the cleaning procedure.

The cleaning procedure is issued by the oxygen service cleaning provider and shall be part of the quality system. This procedure is reviewed and agreed upon by the cleanliness requirement specifier/requester.

The management of change (MOC) process shall be followed if changes are made to the cleaning procedure.

A2 Important elements of a cleaning procedure

A2.1 Parameters considered

The following information is required as input in developing the cleaning procedure:

- equipment/components to be cleaned;
- contaminants to be removed;
- cleanliness level required; and
- location of cleaning work.

For more detailed information on developing a cleaning procedure, see Section 4.

A2.2 Preparation of components and systems to be cleaned

The preparation of the equipment, components, and systems for cleaning shall be described.

Complex components such as valves shall be cleaned before assembly. Assembled components may require dismantling to ensure that all surfaces to be cleaned are accessible for cleaning and cleanliness inspection.

A2.3 Description of the cleaning method

The following details of the cleaning method shall be documented in the cleaning procedure:

- Cleaning agents to be used (for example, steam, aqueous, solvents, semi-aqueous/emulsions);
- If applicable, trade name and concentration of the cleaning agent, temperature of the cleaning bath, and contact time of the component with the cleaning agent;

- The equipment to be used for cleaning (for example, closed cabinet, spray lance, bath, brush, cloth);
- Sequence of the cleaning procedure including all relevant steps. Consideration should be given to the application of the cleaning agent, how the smaller components or equipment are placed into the cleaning basket, and the orientation of individual components or equipment;
- Complete removal of the cleaning agent after cleaning;
- Control of cleaning effectiveness of the cleaning agent. If the same agent is used more than once or to simultaneously clean more than one component, ensure that the cleaning efficiency is not reduced;
- Sequence of rinsing and flushing in order to remove all dissolved contaminants and cleaning agent residues. Rinsing time, temperature, and quality of the rinsing agents, and the method to verify completion of rinsing shall be indicated.
- Describe how draining and drying or purging of the cleaned components will be performed. This is of particular importance for piping and components with dead ends. Ensure that gas used for drying or purging meets the requirements in 7.2.

A2.4 Description of the cleanliness inspection

The following details of the cleanliness inspection shall be documented in the cleaning procedure:

- inspection method(s) used;
- personnel performing inspection and where will it be performed (for example, clean room); and
- acceptance criteria depending on the inspection methods used.

For more detailed information on cleanliness inspection, see Section 8.

A2.5 Handling of nonconformities

- When acceptance criteria are not met, define who shall be informed and who is responsible to manage follow-up measures; and
- Define the consequences of failing the inspection (for example, reclean the part in case of an individual failure or adjust cleaning procedure in case of a systematic problem).

A2.6 Maintaining cleanliness

- Describe the protection measures used during handling, storage, packaging, and transport to maintain cleanliness;
- Instructions for maintaining cleanliness during assembly and final installation; and
- Describe how cleaned parts would be segregated from non-cleaned parts.

For more detailed information on packaging and maintaining cleanliness, see Section 10.

- Describe required labelling for cleaned components to indicate that they are already cleaned and suitable for use in oxygen. For more detailed information on labelling, see Section 11;
- Document cleanliness inspection methods used and the results of the cleanliness inspection. Describe how these documents are maintained. See Section 12; and
- List the documents that will be provided.

A2.7 Validation of cleaning method

Validate that the specified cleanliness level and acceptance criteria can be met after applying the cleaning method described in A2.3. Possible techniques include testing a clean component using solvent extraction and quantification of the residual contaminants or ink test of the cleaned component.

Appendix B — Equipment for oxygen service cleaning using aqueous and solvent cleaning agents
(Informative)

B1 Considerations in the cleaning equipment selection process

The selection of the cleaning procedure and equipment is based on:

- cleaning agent to be used;
- surface properties of the parts to be cleaned;
- shape and geometry of the parts;
- the types and amounts of contaminants; and
- location of cleaning (field versus shop).

The degree of automation, the size, and capacity of the equipment is determined by:

- the size of the parts to be cleaned; and
- the required cleaning rate.

The effectiveness of cleaning is controlled by using test samples, written procedures, and criteria for cleanliness.

B2 Health, safety, and environmental aspects

When using and disposing of aqueous and solvent cleaning agents, see 4.3.2 for environmental considerations and Section 13 for health and safety precautions to be taken.

The water jet from a high-pressure cleaning machine shall be treated like a cutting tool. Suitable protective clothing, gloves, apron, face shield, and goggles shall be worn while carrying out high-pressure cleaning operations. Safety regulations may require two people to operate the machine: one person to operate the high-pressure hose and the other person to shut down the system in case an unsafe condition develops.

Where flammable solvents are used, all electrical equipment, including that of the venting system, shall be rated for the electrical classification as required by applicable national and local regulations.

B3 Cleaning equipment using aqueous cleaning agents

B3.1 Mobile high-pressure cleaning equipment

B3.1.1 Working principle

The aqueous cleaning agent is first applied at low pressure and then the rinsing is performed with high pressure, high-velocity water. For more difficult contaminants, hot water is required. In some equipment, it is possible to inject the dissolved cleaner together with the high-pressure water.

B3.1.2 Applications

High pressure cleaning equipment is suitable for cleaning of large items with easily accessible surfaces, including the outer and internal surfaces of pipe spools (see Appendix C).

B3.2 Wash cabinets for manual cleaning

B3.2.1 Working principle

Wash cabinets can be open or covered by a lid, with or without provision for venting. The pieces to be cleaned are placed on a grid or a perforated plate. The cleaning agent can be manually applied using a soft brush or by hand swabbing and/or sprayed at low pressure. Some types of wash cabinets are equipped with automatic spraying with fixed nozzles or a rotating spraying arm. The cleaning agent, which can be aqueous or solvent, is normally used at room temperature. The cleaning agent drains through a particle filter and is collected into a reservoir for reuse. When the cleaning agent has become too contaminated for use, the reservoir is emptied and cleaned. Rinsing, when necessary, can be performed either inside or outside the wash cabinet.

B3.2.2 Applications

This type of cleaning equipment is more suited for cleaning small parts.

B3.3 Manual immersion cleaning equipment

B3.3.1 Working principle

Depending on their size and geometry, the components or equipment to be cleaned are placed either directly in the immersion tank or in a wire basket inside the tank. The cleaning agent is pumped into the immersion tank until all parts to be cleaned are fully submerged. The cleaning agent can be agitated by injecting dry, oil-free air or nitrogen. Depending on the cleaning agent, heating may be necessary.

To remove air pockets and to ensure that all surfaces of the parts being cleaned are in contact with the cleaning agent, the parts should be moved around periodically by a crane hoist or other means depending on the size and geometry of the parts.

When the cleaning agent has become too contaminated for use, it is drained from the immersion tank into the reservoir. After draining the cleaning agent, parts can be further cleaned using the brushing/spraying device if necessary.

Depending on the type of cleaning agent used, pH monitoring of the used agent may be required to ensure that it remains effective.

After cleaning, rinsing of the parts is normally performed in a separate rinsing bath.

The cleaning effectiveness is strongly dependent on the shape and the quantity of the parts being cleaned. Cleaning effectiveness can be improved by replacing the air or nitrogen injection with ultrasonic energy for better agitation. An alternating current generates ultrasonic vibrations that give rise to cavitation bubbles in the liquid. When they implode, mechanical energy in the form of small jets is created.

Cleaning of small parts is usually performed in wire baskets, which are immersed in the bath. Since some of the ultrasonic energy is lost when the cavitation bubbles collide with the baskets, they should not be made from soft material as these materials absorb more ultrasonic energy.

The liquid in the bath shall be free from gas bubbles as these absorb the ultrasonic energy. Any pumps used should be designed to avoid generating gas bubbles in the liquid. For the same reason, air or nitrogen agitation cannot be combined with ultrasonic energy since the bubbles resulting from air or nitrogen injection would absorb the ultrasonic energy. See Figure B-1.

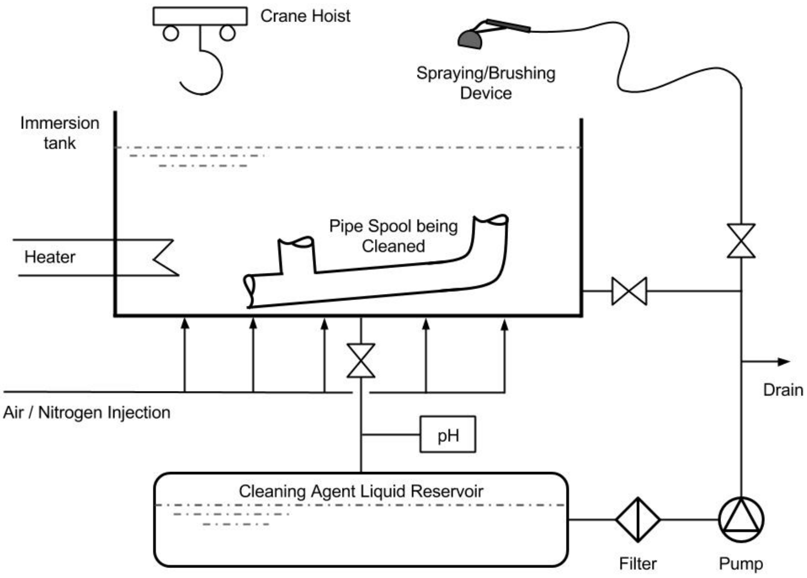

Figure B-1—Example of immersion cleaning equipment with means for brushing and spraying

B3.3.2 Applications

This type of cleaning equipment is suitable for both small and large parts depending on the size of the immersion tank. Parts with narrow and deep cavities can be successfully cleaned with this type of equipment. Ultrasonic agitation is not suitable for porous and soft parts because of their energy absorption properties.

B3.4 Automatic immersion cleaning machines with agitation

B3.4.1 Working principle

The parts to be cleaned are submerged in a bath containing a cleaning agent. Depending on the cleaning agent, heating may be necessary. The cleaning agent may be agitated by injecting dry, oil-free air or nitrogen, by using impellers or circulating liquid. Automatic movement of parts, carried out by rotating or moving the parts up and down in the bath provides additional agitation. Cleaning efficiency can also be improved by replacing the air or nitrogen injection with ultrasonic energy for better agitation. See 4.3.1 for details and precautions.

To handle a large number of parts, they can be continuously moved (for example, in conveyors) from the cleaning bath to one or more rinsing baths. A drying stage can also be integrated into the process.

B3.4.2 Applications

Automatic immersion cleaning is appropriate for small and medium size parts. Provided efficient agitation can be arranged, parts with narrow and deep cavities can be successfully cleaned in this type of equipment.

B3.5 Jet/spray cabinet cleaning machines

B3.5.1 Working principle

This type of machine uses a combination of immersion, flushing, and spraying. Immersion is obtained by increasing the cleaning agent liquid level. During this phase, turbulence is created in the liquid by using jet flushing nozzles. The parts to be cleaned are placed in a basket or drum which can be rotated or rocked in the cleaning liquid while simultaneously flushing or spraying from the nozzles. The mechanical impact and powerful agitation results in improved cleaning efficiency.

The cleaning stage is followed by rinsing with water from a separate tank in the same unit. It can also be equipped with facilities for drying.

The cleaning sequence is automatically controlled and can be changed to suit different cleaning situations.

B3.5.2 Applications

Small and medium size parts can be successfully cleaned in this type of cleaning equipment. Typical examples are closely packed parts with complicated shapes, cavities, and crevices.

B4 Cleaning equipment using solvents

B4.1 Vapor degreasing equipment using solvents

B4.1.1 Working principle

The solvent is heated to its boiling point in the sump of the vat with the vapor rising upwards. The parts to be cleaned are suspended in the vapor phase. The solvent condenses on the surfaces of the parts, dissolving oil and grease, which drain back to the sump of the vat. Most of the remaining vapor is condensed on the cooled walls in the upper part of the vat (the cooling zone).

Distillation of the cleaning solvent in the sump ensures that clean solvent condenses on the parts, even if the solvent in the sump is heavily contaminated.

During the cleaning process, parts with cavities shall be rotated or oriented to drain any solvent that has condensed and collected in the cavities.

The cleaning process stops when the temperature of the components or equipment reaches the boiling point of the solvent. If this happens before the parts are adequately cleaned, the parts have to be cooled down before the degreasing process can be restarted.

Regular checks of the solvent in the sump are necessary to ensure that the solvent remains suitable for safe and effective use.

B4.1.2 Applications

Vapor degreasing can be applied to many different components or equipment and geometries as the vapor can reach and condense even on hard to reach surfaces. Problems can occur with small and thin parts, which can quickly heat up to the boiling temperature of the cleaning agent.

B4.2 Immersion cleaning equipment using solvents

B4.2.1 Working principle

This type of equipment is typically closed to keep the operator separated from contact with the solvent. The parts to be cleaned are immersed into the solvent, which is agitated by stirring or by ultrasonic energy. Spraying is also used.

The parts are normally loaded into the empty vat, the lid of the cleaning machine closed, and the solvent pumped in from a separate closed solvent storage tank. After the cleaning cycle is completed, the solvent is drained from the vat back to the solvent storage tank. The solvent vapors are evacuated by a venting system before the lid or door is opened and the parts are removed.

B4.2.2 Applications

This type of cleaning equipment is mainly used for small parts and parts with narrow cavities.

B4.3 Wash cabinets for manual cleaning using low volatile solvents

B4.3.1 Working principle

The same type of wash cabinets used for aqueous cleaning agents can also be used with low volatile solvents, provided they are equipped with venting systems and the risk associated with solvents are addressed.

B4.3.2 Applications

This type of cleaning equipment is suitable mainly for cleaning of small parts where all surfaces can be directly inspected.

B4.4 Immersion cleaning equipment using emulsion cleaning agents

B4.4.1 Working principle

The same type of cleaning equipment used for aqueous cleaning agents can be used with water-based emulsion cleaning agents, provided that the risks associated with solvents are addressed.

It is important that the water rinsing stage, which follows the cleaning stage, removes all residues.

When water-free solvents with added emulsifiers are used, the cleaning is considered to be solvent cleaning. The cleaning equipment shall be the same as for cleaning with pure solvents.

B4.4.2 Applications

This type of cleaning equipment can be used for the same type of parts as for aqueous cleaning. The penetration into narrow cavities is better for emulsion cleaning agents than for pure aqueous cleaning agents.

B5 Auxiliary equipment

B5.1 Particle removal from cleaning agents

The removal of particles from recirculating cleaning agents is essential for minimizing wear on the pumps and valves of the cleaning equipment and for preventing clogging of the spray nozzles.

The particles can be removed as sediment from the tanks or by using inline filters.

B5.2 Oil separation

The lifetime and efficiency of cleaning agents depends on maintaining the chemical composition of these agents. By removing oil contaminants from the recirculating cleaning agents, their usage can be prolonged and their wastage minimized.

The oil contamination in the used cleaning agent can exist as free oil or as an emulsion. Free oil can be separated by means of gravity, by filtration, or adsorption. Examples of equipment used to remove free oil include oil skimmers, coalescence filters, and oil adsorbing bag filters.

Emulsified oil can be removed by micro- or ultra-filtration, chemical decomposition, adsorption, or biological treatment.

B5.3 Vapor emission control

The control of vapor emissions from solvent-based cleaning equipment is essential for the protection of personnel and the environment.

Carbon or molecular sieve adsorbers or cryogenic condensation equipment can be used to remove solvent vapours from the vents of the cleaning equipment.

Appendix C — Example of a cleaning procedure for carbon steel piping (Informative)

This cleaning procedure provides an example of how to clean new carbon steel piping for oxygen service including spool pieces, elbows, tees, etc., before welding.

Cleaning of carbon steel pipelines is not addressed in this Appendix. Specific tools and procedures may be required.

C1 Tools and equipment

Brushes, cloths, grit blasting equipment, high pressure water jet spray wash machine, lighting, inspection lamps (white light and black light) may be required to clean and inspect carbon steel piping. Immersion cleaning equipment may be necessary if this method is adopted for cleaning. Personnel performing the cleaning shall wear PPE. See CGA P-44 [23]. Personnel performing cleaning shall work with clean hands, footwear, and clothing (uncontaminated by oil, grease, or dirt).

C2 Cleaning agent selection

In case cleaning agents are used, nontoxic, biodegradable, water soluble agents are preferred. In all cases, follow the manufacturers recommendations.

C3 Cleaning

a) Oxygen service cleaning of the piping is done on completion of prefabrication work including preparation for welding (before applying the primer paint to external surfaces) and before installation/assembly in order to ensure the best possible internal cleanliness;

b) The inner surfaces of the piping are blasted to white metal by bead or virgin grit-blasting. The propellant air shall be dry and oil-free. Steel shot blast shall only be used if its complete removal can be ensured as failure to remove all the shot can result in unacceptable consequences in oxygen service. Blowout or vacuum all loose particles including all grit blasting material with dry, oil-free air or nitrogen. Spot clean by hand wiping with solvent, if necessary. A slight discoloration resulting from a light film of oxide is acceptable;

c) Pressurized spray washing may be considered as a possible alternative to grit blasting. See Figure C-1. High pressure water wash machines with special nozzles spraying radially are suitable for cleaning the inner surfaces of piping. The water quality for washing shall be ensured by filtration. After cleaning, immediate draining of the water and drying is necessary to remove all moisture;

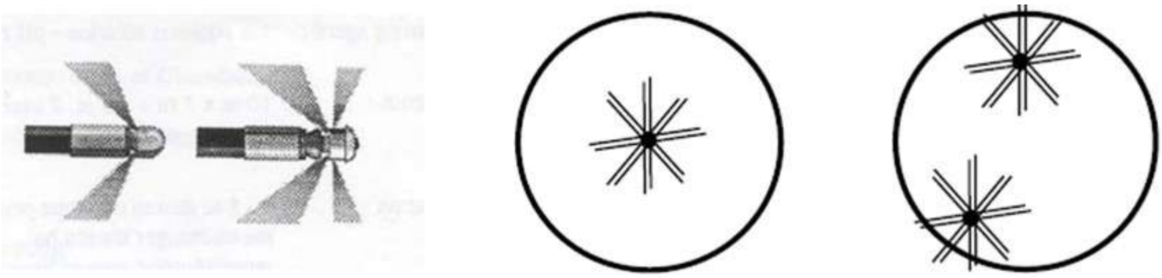

Figure C-1—Example of high pressure water wash machines

d) Another cleaning method is the immersion of the piping spools in an aqueous cleaning agent bath with some type of agitation. Washing of the external surface and preliminary cleaning (air blow) of internal surfaces should be performed prior to dipping in the immersion bath to avoid unnecessary pollution of the cleaning agent, which would help to prolong its service life. Once cleaning is completed, the piping spools shall be rinsed immediately with water and dried;

e) In climates where rusting before installation is likely, alkaline passivation of the piping inner surfaces (for example, using aqueous sodium hydroxide) may be considered;

f) If the external surface of the piping spools need to be painted, primer paint should be applied after the completion of the oxygen service cleaning (particularly in case of cleaning by immersion in a cleaning agent or grit blasting). Care shall be taken to prevent contamination of the piping inner surfaces during the painting operation;

g) Weld the piping while maintaining its cleanliness by avoiding contact with dirty surfaces, wearing clean gloves, not introducing foreign materials, and observing general clean assembly practices. Use of a gas tungsten arc welding (GTAW)/tungsten inert gas (TIG) root-pass weld is recommended. Avoid the use of tools that can bring contamination to the inner surfaces. Inspection and removal of loose debris is essential;

h) After the piping is installed, high quality pressure blowing of the piping circuit with dry, oil-free air is required to remove particles, filing dust, burrs, swarf, scale, rust, etc.; and

i) Cleaning by circulation of a cleaning agent (typically an aqueous solution) after installation/assembly of the pipe systems, for example due to contamination during operation, may require additional levels of expertise and/or approval of written procedures. Care shall be taken to remove all the cleaning agent, and thoroughly rinse and dry the cleaned piping circuit. Pay attention to low points and branches and the potential for the cleaning agent or residues to remain in these areas.

C4 Inspection

Cleaned piping spools shall be inspected for compliance to cleanliness requirements. Inspection methods include direct visual inspection, ultraviolet inspection, and wipe testing. If contaminants are observed, the piping shall be recleaned. For more information, see Section 8.

C5 Packaging, labelling, and storage

Maintain cleanliness by sealing the pipe ends with caps, plugs, blind flanges, etc., that have been cleaned for oxygen service. In climates where rusting is likely, desiccant bags may be mounted inside the closure cap. The pipe ends may also be sealed with clean plastic wrapping. Label each clean piping spool with CLEANED FOR OXYGEN SERVICE. For more information, see Section 11. Ensure pipe caps or plugs are secured and cannot fall off during storage. Store pipe spool pieces in a dirt-free area to avoid contamination.

Appendix D—Example of a cleaning procedure for valves, instrumentation, and piping components (Informative)

This appendix provides an example of how to clean valves, instrumentation, and piping components whether new or removed from service, for example, for maintenance.

This cleaning method can be used on metallic and non-metallic materials in oxygen service.

D1 Cleaning agent selection and equipment

The following cleaning agents and equipment may be used:

- Water-based detergents in baths, with or without mechanical agitation including ultrasonic agitation or using industrial dishwashing machines; and
- solvents through immersion in baths or wiping with a cloth.

D2 Cleaning method

Cleaning valves, instrumentation, and piping components may involve the following steps:

a) Field disassembly (if applicable):

  - Removing the item from the process for cleaning requires care to avoid contamination of the item or the process
  - Clean the exterior of the item before disassembly by water washing, scrubbing, etc.
  - Bag the item; and
  - Double bag and secure tightly the open ends of the process.

b) Inspect the item before oxygen cleaning—Before disassembly and oxygen cleaning, inspect the item to confirm the need for cleaning. Cleaning an in-use item may not be necessary if inspection can confirm it is already in an acceptable state of cleanliness;

c) Preclean the item before oxygen cleaning—If the item needs oxygen cleaning, precleaning to remove as much contamination as possible before and during disassembly can be helpful for final cleaning. When disassembly is required, personnel should follow a written plan. After precleaning, items should be visually clean and not grossly contaminated by oils and greases;

d) Cleaning—All cleaning, inspection, and assembly activities until packing, including activities in the field, shall take place in a designated area for clean work. All the tools, clothes, and equipment used for oxygen cleaning, reassembly, and packaging shall be clean to avoid recontamination of the cleaned item and parts of the items. Personnel performing cleaning shall work with clean hands and work clothing (uncontaminated by oil, grease, or dirt).

   Cleaning shall be completed in accordance with an approved cleaning procedure. After cleaning, rinsing, drying, and/or purging is necessary to remove all cleaning agents and their residues;

e) Inspection—Cleaned parts shall be inspected for compliance. Methods used are bright white light, UV light, and wipe test. For more information, see Section 8;

f) Assembly—Personnel performing assembly should follow a written plan;

g) Packaging and labelling—Cleaned items shall be packaged to prevent contamination. See Section 10.

  - A label shall be visible from outside the package indicating CLEANED FOR OXYGEN SERVICE. The number of desiccant bags, if any, shall be indicated on the label. See Section 11; and
  - Cleaning history may be required, see 12.1 for information on recordkeeping.

Appendix E — Example of a cleaning procedure of a tubular heat exchanger (Informative)

This appendix provides an example of how to clean a shell and tube heat exchanger where oxygen flows inside the tubes (typical configuration for high pressure oxygen). The objective is to clean the internal of headers, tubesheet, and inner surfaces of the tube bundle when installed in the shell.

This cleaning method can be used on carbon steel headers and nozzles as well as copper alloy, nickel alloy, or stainless-steel tubing and tubesheets.

E1 Tools and equipment

- Cleaning agent storage tank;
- Cleaning agent circulation pump. Wetted surfaces shall be oil-free. It shall be able to provide sufficient flow to achieve high velocity (i.e., turbulent flow) inside the tubes to enhance cleaning;
- Heater. Depending on the cleaning agent, heating it can increase the degreasing capability of the agent. When cleaning agent temperatures are greater than 104 °F (40 °C), measures shall be taken to protect personnel;
- Filter. On the inlet to the heat exchanger, commonly used screen sizes are 150 microns and finer; and
- Interconnecting piping and valves.

See Figure E-1.

Cleaning equipment materials of construction shall be compatible with the cleaning agent.

Personnel performing the cleaning shall wear appropriate personal protective equipment. See CGA P-44 [23].

Waste treatment units or collecting tanks, pits or basins for disposal of the used cleaning agents may be required in order to meet national and local environmental regulations.

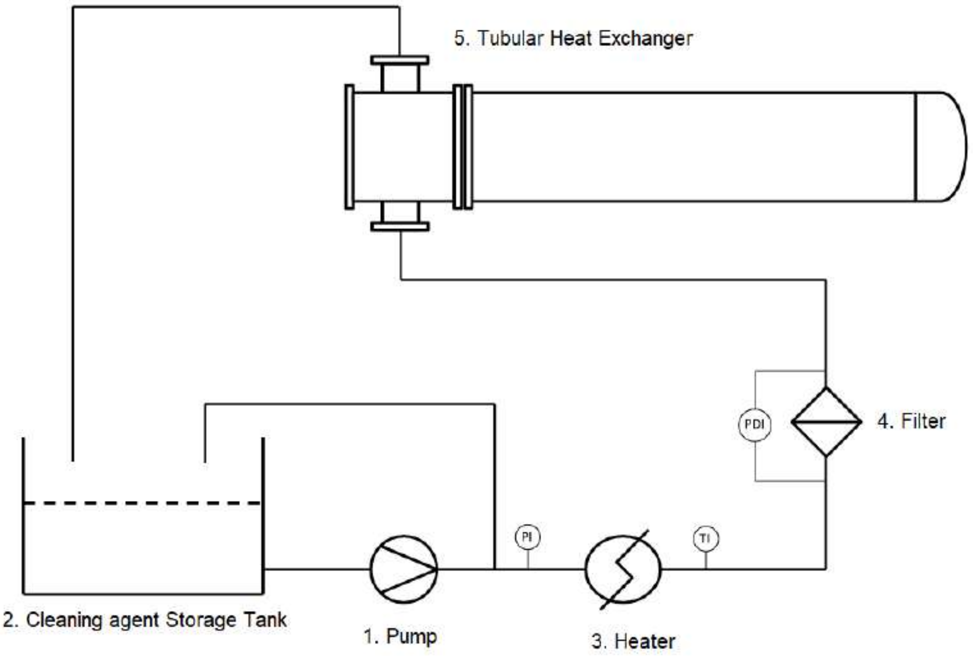

Figure E-1—Example of tools and equipment for cleaning a tubular heat exchanger

E2 Cleaning agent selection

Aqueous cleaning agents are commonly used for cleaning the heat exchanger.

In all cases, follow manufacturers recommendations regarding solution concentration, temperature, compatibility of materials, and required safety precautions.

E3 Precleaning

Figure E-1 shows the circuit to be installed for the cleaning process. To avoid introducing contamination from the circuit into the heat exchanger, the circuit shall be cleaned and inspected prior to cleaning of the heat exchanger. Forced circulation of the cleaning agent described in this Appendix may be used to clean the circuit by bypassing the heat exchanger.

When using carbon steel headers for the heat exchanger, surface treatments may be required to remove rust and scale.

E4 Cleaning

The cleaning agent shall be prepared according to manufacturer’s instructions. Normally, water can be used for preparing aqueous cleaning agents. Water used shall have chloride levels less than 50 parts per million (ppm) when cleaning stainless steel.

Cleaning agent is circulated through the heat exchanger and heated when necessary. A turbulent flow (Reynolds number approximately 3000 to 4000) is recommended to enhance the degreasing.

Circulating the cleaning agent through the heat exchanger for several hours is normally required (depending on the degree of contamination and the cleaning agent used).

Cleanliness of the cleaning agent should be monitored to ensure continued cleaning effectiveness (for example, visual comparison of the agent in the storage tank to a clean sample of the cleaning agent). If the cleaning agent is found to be grossly contaminated, replace with fresh cleaning agent.

E5 Rinsing

After cleaning, the heat exchanger and cleaning system shall be emptied of cleaning agent. Immediately fill the storage tank with water and circulate for at least 2 hours. Empty the heat exchanger and cleaning system and immediately fill with water at least two additional times to ensure the complete removal of the cleaning agent. At the end of rinsing, verify that the water exiting the heat exchanger has the same pH as the water used for rinsing. If not, continue the rinsing process. Once rinsing is completed, drain the water.

E6 Drying

Immediately after draining the water, disconnect the water circuit and connect dry, oil-free air or nitrogen to the inlet of the heat exchanger. The gas flow shall continue until the dew point of the exit gas is within 3 °C of the inlet gas.

E7 Cleanliness inspection

Inspection methods include direct visual inspection of accessible parts (white light and UV light) and wiping. Solvent extraction of a representative tube may also be performed. If solvent extraction is performed, all solvent shall be completely removed by purging in order to consider the cleaning operation complete.

Results of the inspection shall be recorded (see 12.1).

E8 Cleanliness preservation and labelling

Use blind flanges or caps that have been cleaned for oxygen service to seal the heat exchanger tube side connections. Desiccant bags may be mounted inside the closure cap. Label the equipment with a visible and securely attached tag indicating CLEANED FOR OXYGEN SERVICE. See Sections 10 and 11.

Appendix F — Example of a cleaning procedure for a shop fabricated carbon steel vessel (Informative)

This cleaning procedure provides an example of how to clean for oxygen service a new carbon steel shop fabricated vessel that can be entered and its associated nozzles.

F1 Tools and equipment

Brushes, cloths, grit blasting equipment, high pressure water jet spray wash machine, lighting, inspection lamps (black light and white light) may be required to clean and inspect the vessel. Personnel performing the cleaning shall wear PPE. See EIGA Doc 136 [23]. Personnel performing cleaning shall work with clean hands, footwear, and clothing (uncontaminated by oil, grease, or dirt).

F2 Cleaning agent selection

Nontoxic, biodegradable, water soluble agents are preferred. The use of solvents should be minimized and avoided if possible. In all cases, follow the manufacturer's recommendations.

F3 Cleaning

Complete all welding, cutting, forming, and bevelling. After welding, the internal vessel surfaces are blasted to white metal by bead or virgin grit blasting. The propellant air shall be dry and oil-free. Steel shot blast shall only be used if the complete removal can be ensured as failure to remove all the shot can result in unacceptable consequences in oxygen service. A slight discoloration resulting from a light film of oxide is acceptable.

Visually inspect all interior surfaces and brush or scrape away any dirt, dust, chips and other debris. Any accumulated dirt on the tank bottom can be removed by sweeping or vacuuming. Before the final closure weld is performed, wipe away with a solvent cleaning agent all visible grease, oil spots, markings, and paint.

Pipe spools should be cleaned for oxygen service before being attached to the vessel.

Inspection methods include direct visual inspection, UV inspection, or wiping, as appropriate. The entire internal surface shall be inspected following one or more of these methods. Pay particular attention to openings and piping penetrations.

F4 Related procedures

When the vessel requires a hydrotest after oxygen cleaning, use water. Corrosion inhibitors in the water shall only be used upon verification that any expected residue left behind is compatible with oxygen for the residue quantity and conditions that will exist in the vessel. A final drying step shall be performed immediately after draining the vessel.

After drying, desiccant bags may be mounted inside the vessel. Use blind flanges or caps that have been cleaned for oxygen service to seal the openings of the vessel. Label the equipment with a visible and securely attached tag indicating CLEANED FOR OXYGEN SERVICE. See Section 10.

Appendix G—Example of a cleaning procedure for a shop fabricated cryogenic tank (Informative)

This cleaning procedure provides an example of how to clean a new cryogenic stainless steel shop fabricated vessel and its associated piping for oxygen service.

G1 Tools and equipment

Brushes, cloths, high pressure water jet spray wash machine, lighting, inspection lamps (black light and white light) may be required to clean and inspect the vessel. Personnel performing the cleaning shall wear PPE. See EIGA Doc 136 [23]. Personnel performing cleaning shall work with clean hands, footwear, and clothing (uncontaminated by oil, grease, or dirt).

G2 Cleaning agent selection

Nontoxic, biodegradable, water soluble agents are preferred. Pickling (acid cleaning) and passivation agents and solvents may also be used. The use of solvents should be minimized and avoided, if possible. In all cases, follow the manufacturer’s recommendations.

G3 Precleaning

Complete all welding, gouging, and grinding. Remove all weld slag, carbon arc spray, carbon contamination, burrs and other welding related contamination adhering to the tank interior surfaces. Use stainless steel power brushes or hand wire brushes, aluminium oxide grinding disks, flapper wheels or belt sanders that have only been used on stainless steel surfaces.

Before the final closure weld is performed, wipe away all visible grease, oil spots, markings, and paint. Visually inspect all interior surfaces and brush or scrape away any dirt, dust, chips, and other debris. Any accumulated dirt on the tank bottom can be removed by sweeping or vacuuming.

G4 Cleaning

After the final closure weld is completed, initial degreasing with a cleaning agent and rinse with water is performed. Pickling (acid cleaning) of the vessel may then be done by spraying method. Pickling of the piping may be accomplished by the immersion method. Rinse by spraying water with the help of high pressure water jet machine. All water used shall have chloride levels less than 50 ppm.

After pickling, passivation is carried out. All of the passivation agent is then removed by rinsing with water.

NOTE Piping should be cleaned twice. Once after bending and the second time after prefabrication and prior to welding to the vessel as noted previously.

As required, final degreasing with a cleaning agent and rinse with water is then completed. Corrosion inhibitors in the water shall only be used upon verification that any expected residue left behind is compatible with oxygen for the residue quantity and conditions that will exist in the vessel.

Items which have readily accessible surfaces can be cleaned by wiping. The vessel is then dried before a final inspection.

Inspection methods include direct visual inspection, UV inspection, or wiping, as appropriate.

G5 Related procedures

When the vessel requires a hydrotest after oxygen cleaning, use water. Corrosion inhibitors in the water shall only be used upon verification that any expected residue left behind is compatible with oxygen for the residue quantity and conditions that will exist in the vessel. A final drying step shall be performed immediately after draining the vessel.

After drying, to maintain cleanliness, the vessel may either be purged and pressurized with a dry, oil-free air or nitrogen or provided with desiccant bags. Use blind flanges or caps that have been cleaned for oxygen service to seal the openings of the vessel. Label the equipment with a visible and securely attached tag indicating CLEANED FOR OXYGEN SERVICE. See Sections 10 and 11.

Appendix H—Example of a cleaning procedure for a field fabricated bulk storage tank (Informative)

This appendix provides an example of how to clean a stainless steel field fabricated tank and its associated piping to its outlet flanges. The objective is to clean the inner tank and pipe interior surfaces for oxygen service while using the minimum quantity of cleaning agent.

H1 Tools and equipment

Brooms, brushes, cloths, mops, high pressure water jet spray wash machine, ladders, scaffolds, lighting, inspection lamps (black light and white light) may be required to clean and inspect the tank. Personnel performing the cleaning shall wear appropriate PPE. See EIGA Doc 136 [23]. Personnel performing cleaning shall work with clean hands, footwear, and clothing (uncontaminated by oil, grease, or dirt).

H2 Cleaning agent selection

Nontoxic, biodegradable, water soluble agents, are preferred. The use of solvents should be minimized and avoided if possible. In all cases, follow the manufacturer’s recommendations.

H3 Precleaning

Complete all welding, gouging, and grinding. Remove all weld slag, carbon arc spray, carbon contamination, burrs and other welding related contamination adhering to the tank interior surfaces. Use stainless steel power brushes or hand wire brushes, aluminium oxide grinding disks, flapper wheels, or belt sanders that have only been used on stainless steel surfaces.

Wipe away all visible grease, oil spots, markings, and paint. Visually inspect all interior surfaces and brush or scrape away any dirt, mud, dust, chips, and other debris. Any accumulated dirt on the tank bottom can be removed by sweeping or vacuuming.

H4 Cleaning

It is preferable to clean the roof while accessible from grade prior to installation. Wash the entire surface using water. Water used shall have chloride levels less than 50 ppm. Inspect the roof surface for cleanliness. Remove all hydrocarbon indications by scrubbing with a cleaning agent. Rinse with water and re-inspect. Inspections may require closing off the perimeter of the roof to block off the ambient light.

After the roof assembly has been fully welded to the inner tank shell, the inner tank shell is cleaned on a ring by ring basis. Each ring is washed, rinsed, and inspected from top to bottom. Water accumulating on the tank bottom can be removed by mops and buckets or drained out of one of the liquid lines and disposed per environmental regulations. The inner tank bottom is cleaned last in a fashion similar to the shell walls.

Annular space piping should be cleaned prior to installation using a cleaning agent and then rinsed with water to flush the lines. After rinsing the lines, clean, lint-free cloths can be drawn through the pipes to dry and inspect for final cleanliness. Liquid bottom pipes require a final flush, cleaning, and rinsing after the bottom of the inner tank bottom has been cleaned. A final cleaning of liquid bottom pipes should be completed by drawing clean, lint-free cloths through the pipe to confirm all debris has been removed. Special attention shall be paid to any standpipes or sidewall penetrations.

Inspection methods include direct visual inspection, UV inspection, wiping, or mirror test, as appropriate.

The outer surface of the inner tank and inner surface of the outer tank should be spot cleaned to remove gross contaminations of hydrocarbons. The annular space is swept “broom clean” via industrial vacuum cleaners, brooms, etc. to remove all paper, wood, metal chips, plastics, foreign objects, and other debris.

H5 Related procedures

The tank will require a hydrotest after cleaning using water with chloride levels less than 50 ppm, which should be released unrestricted through the liquid nozzles to flush out any dirt particles. A final drying step and closure of tank openings is required. A final inspection after hydrotesting and drying may be necessary.