Engineering Procedure

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Cleaning of Plant Equipment and Piping

Document Responsibility: Corrosion Control Standards Committee

Contents

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1 Scope

1.1 This procedure defines the minimum requirements for cleaning new and existing Plant equipment and piping systems to remove oil, grease, preservatives, rust, corrosion products, and mill & mineral scales. It includes, but is not limited to, cleaning of heat exchangers, coolers, condensers, refrigerant systems, vessels, columns, towers, storage tanks, plant piping, MEDs, TEG, MEG, DEA, MEA, MDEA, DGA, AGR, and any other amine systems. Refer to SAEP-1025 for cleaning of steam generation equipment (boilers, heat recovery steam generators, etc.) and associated piping.

1.2 This procedure defines the responsibilities of the various departments involved in the pre commission and cleaning of plant equipment and piping. It outlines requirements for cleaning, the criteria for selecting specific cleaning procedures, and steps involved in various cleaning procedures.

1.3 This procedure does not override an equipment manufacturer's cleaning recommendations, especially where warranty rights are involved. Differences shall be questioned and resolved by the proponent.

2 Conflicts and Deviations

2.1 Any conflicts between this Procedure and other applicable Saudi Aramco Engineering Procedures (SAEPs), Saudi Aramco Engineering Standards (SAESs), Saudi Aramco Materials System Specifications (SAMSSs), Saudi Aramco Standard Drawings (SASDs), or industry standards, codes, and forms shall be resolved in writing by the Company or Buyer Representative through the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

2.2 Direct all requests to deviate from this Procedure in writing to the Company or Buyer Representative, who shall follow internal company procedure SAEP-302 and forward such requests to the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

3 Applicable Documents

The equipment cleaning covered by this procedure shall comply with all Saudi Aramco Mandatory Engineering Requirements and industry codes and standards, with particular emphasis on the documents listed below. Unless otherwise stated, the most recent edition of each document shall be used.

3.1 Saudi Aramco References

Saudi Aramco Engineering Procedures

SAEP-302	*Instructions for Obtaining a Waiver of a Mandatory Saudi Aramco Engineering Requirement*
SAEP-327	*Disposal of Wastewater from Cleaning, Flushing, and Dewatering Pipelines and Vessels*
SAEP-1025	*Chemical Cleaning of Steam Generation Systems*

Saudi Aramco Engineering Standards

SAES-A-007	*Hydrostatic Testing Fluids and Lay-Up Procedures*
SAES-A-103	*Protection of the Marine Environment*
SAES-G-116	*Cleanliness Standard for Lube/Seal Oil and Fluid Power Systems*
SAES-L-350	*Construction of Plant Piping*

Saudi Aramco Materials System Specification

01-SAMSS-017	*Auxiliary Piping for Mechanical Equipment*

Saudi Aramco General Instruction

GI-0150.100	*Hazardous Materials Communication (HAZCOM) Program*

Saudi Aramco Hazardous Waste Code (SAHWC)

Saudi Aramco Safety Management Guide

06-003-2013	*Job Safety Analysis*

Saudi Aramco Best Practices

SABP-A-036	*Corrosion Monitoring Best Practice*
SABP-A-051	*Supplement to Chemical Cleaning Procedures*
SABP-A-072	*Materials Selection and Cleanliness of Piping Systems in Oxygen Service*

3.2 Industry Codes and Standards

American Society for Testing and Materials

ASTM G93	*Standard Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments*

NACE International

NACE TM 0169	*Laboratory Corrosion Testing of Metals*
NACE TM 0193	*Laboratory Corrosion Testing of Metals in Static Chemical Cleaning Solutions at Temperatures Below 93°C (200°F)*

4 Definitions and Abbreviations

Alkaline Solution: Solutions of a soluble base that has a pH greater than 7 such as soda ash.

Austenitic Stainless Steels: Chromium and nickel bearing ferrous alloys noted for their resistance to corrosion.

Blend Filling: A method of filling a vessel with chemical cleaning solution in which the chemical concentrate (in liquid form) is metered into the filling line at such a rate as to maintain the desired concentration level in the liquid entering the vessel.

Chelating Agents: Chemicals such as Ethylene Diamine Tetra Acetic Acid, $C_{10}H_{16}N_2O_8$ (EDTA), etc.

DEA: Diethanolamine

DGA: Diglycolamine

Flushing: Cleaning a surface by the application of copious supplies of water under pressure.

Inhibitor: A compound that retards or stops an undesired chemical reaction such as corrosion or oxidation.

JSA: Job Safety Analysis

LEL: lower explosive limit

M-Alkalinity: Methyl orange alkalinity, which exists above the pH range of 4.2 to 4.4.

Mill Scale: A layer of iron oxide consisting of magnetite (Fe_3O_4) on the surface of hot rolled steel.

Mils per Year (mpy): A measurement of corrosion penetration in one thousandths (0.001) inch per year.

MDEA: Methyldiethanolamine

MEA: Monoethanolamine

MEG: Monoethylene glycol

Passivation: A treatment for steel surfaces to give greater resistance to corrosion by shifting the normal electrochemical potential of the metal with a thin film of oxide.

Sacrificial Valve: A substitute valve used in a chemical cleaning operation in place of the regular valve to prevent corrosion damage to that valve.

Surfactant: A compound, when dissolved in water, reduces interfacial tension between the liquid and a solid.

TEG: Triethylene glycol

5 Roles and Responsibilities

5.1 Saudi Aramco Project Management Team (SAPMT)

For new construction, SAPMT shall be responsible to:

5.1.1 Ensure the implementation of this procedure and compliance with all requirements.

5.1.2 Facilitate and resolve any issues related to the implementation of this procedure with other Saudi Aramco organizations.

5.1.3 Coordinate and obtain approval of chemical cleaning procedures from the Approval Authority (Proponent).

5.1.4 Arrange pre-cleaning and post-cleaning inspection with the Inspection Agency.

5.1.5 Maintain a permanent written record of the cleaning operation, i.e., temperatures, pressures, corrosion rates, time and date of cleaning, chemical additions, and results of chemical cleaning analysis.

5.2 Execution Authority

The execution authority shall be the construction agency for new constructions, while the plant maintenance shall be the execution authority for existing facilities responsible to:

5.2.1 Prepare the equipment mechanically.

5.2.2 Provide maintenance support during the cleaning operation.

5.2.3 Coordinate with Operations Engineering to develop scope of work for obtaining contractor’s services.

5.2.4 Coordinate cleaning operations and obtain approved contractor services.

Commentary Note:

> *Contact CSD/MED/Corrosion Engineering Group for the Saudi Aramco's approved list of cleaning contractors.*

5.2.5 Ensure the implementation of this procedure and compliance with all requirements.

5.2.6 Coordinate a pre-job meeting with the chemical cleaning contractor, execution authority, and concerned parties before the start of the chemical cleaning job.

5.2.7 Coordinate disposal of all waste water and chemical solutions as per SAEP-327, SAES-A-103, and SAHWC.

5.2.8 Provide all resources and materials required to implement the hydrostatic test and lay-up procedure, refer to SAES-A-007. This includes, but is not limited to, installing temporary piping and equipment and providing necessary labor.

5.2.9 Report regularly all cleaning operations' results to approval authority.

5.2.10 Provide all records to SAPMT for each cleaning operation and shall be included in the Project Records turnover to SAPMT at the project end.

5.3 Approval Authority (Proponent)

The approval authority for new construction and existing facilities shall be the Engineering Superintendent (or his delegate). The approval authority shall be responsible to:

5.3.1 Work with plant Maintenance to develop scope of work for obtaining contractor's services.

5.3.2 Prepare necessary operation procedures and advise the foreman of the plant during the chemical cleaning of the equipment.

5.3.3 Act as a technical representative to address any technical queries during the cleaning operation.

5.3.4 Perform a Job Safety Analysis as per Saudi Aramco Safety Management Guide #06-003-2013.

5.3.5 Review and approve the cleaning procedures from Saudi Aramco approved service providers.

5.3.6 Monitor the quality of the chemical cleaning fluids during the cleaning activities.

5.3.7 Ensure adequate safety procedures and precautions are taken.

5.3.8 Notify Loss Prevention Department to review safety during cleaning, as necessary.

5.3.9 Seek clarification, consultation, and technical support from CSD, as needed.

5.3.10 Coordinate sampling and testing during cleaning activities with Area and Regional Laboratories, if needed.

5.3.11 Maintain Log Sheets of cleaning operation. Typical log sheets include what is shown in Appendix B, contractor's log sheets and the on-line corrosion monitoring charts indicating corrosion rates vs. time, and any other required parameters.

5.4 Inspection Authority

5.4.1 The inspection authority for new constructions shall be the responsible Projects Inspection Division (PID)/Inspection Department (ID).

5.4.2 For existing facilities, the proponent's Operations Inspection shall be the inspection authority. The inspection authority shall be responsible to:

- Inspect equipment before and after cleaning.
- Get and keep the corrosion monitoring records from the contractor.
- Maintain history of equipment chemical cleaning and incorporate relevant reports and data into permanent plant records.
- Monitor corrosion using weight loss coupons or equivalent.

5.5 Consulting Services Department (CSD)

5.5.1 CSD shall provide clarification, consultation, and technical support, as needed, for the general requirement of this procedure.

5.5.2 Shall only review and approve new chemical cleaning methods not specifically discussed in this procedure prior to starting the chemical cleaning activities.

5.5.3 CSD shall certify new cleaning contractors and recertify existing ones.

5.6 Research and Development Center (R&DC)

5.6.1 Test, evaluate and verify new chemical cleaning products, corrosion inhibitors effectiveness, and perform chemical analysis, if required.

5.6.2 The tests shall be conducted at the recommended chemical dilution ratios and control parameters in terms of concentration, temperature, pH, and duration as follows:

1. Corrosion Test
    - Test the chemical per NACE TM0193 and NACE TM0169 for common materials of construction
2. Performance test only for the decontamination chemicals:
    - To demonstrate removal of hydrocarbon sludge
    - To get LEL and H_2S levels to zero and benzene to < 0.5 ppm
    - To determine the biodegradability of the products
3. Performance tests only for the cleaning products and corrosion inhibitors:
    - To show the effectiveness of their applications
    - To determine the biodegradability of the products

5.6.3 Recommend a third-party lab for testing cleaning chemicals, if required.

5.6.4 Provide consultation advice on request.

5.7 Area and Regional Laboratories

5.7.1 Perform chemical analysis, compatibility of blended chemicals, and monitor and log chemical cleaning analyses during cleaning activities, if needed.

5.7.2 Verify the purity of acids and chemicals used for chemical cleaning on request.

5.8 Loss Prevention Department

5.8.1 Audit cleaning operations and permits.

5.8.2 Advise on field safety precautions on request.

5.9 Chemical Cleaning Contractor

The full list of contractor responsibilities shall be stated in the chemical cleaning contract. Below are major responsibilities:

5.9.1 Submit procedures and documents per Appendix A.

5.9.2 Supply all chemicals, inhibitors, auxiliary pumping and heating equipment, corrosion monitor as required, and the necessary personnel for chemical cleaning, including a qualified chemist for chemical analysis during the chemical cleaning

5.9.3 Clean the specified systems to meet or exceed the acceptance criteria for effective cleaning as outlined in Section 12.

5.9.4 Conduct on-line corrosion rate monitoring as per SABP-A-036.

5.9.5 Dispose all waste water and chemical solutions as per SAEP-327, SAES-A-103, and SAHWC.

5.9.6 Submit a final chemical cleaning report upon completion. The report shall include, but is not limited to, implemented cleaning procedure(s), cleaning log sheets, findings, cleaning parameters, and lessons learned.

6 Criteria for Cleaning

It is necessary to clean new equipment initially and periodically thereafter for its efficient operation, corrosion control and prevention of fouling related failures. The interior of the piping for below specific services shall be cleaned after hydrostatic pressure testing to remove oil, grease, preservatives, rust and mill scale per approved procedures. Some of these services and other are included in 01-SAMSS-017, SAES-L-350 and SAES-G-116.

- Boiler feed water, steam condensate and steam lines.
- Lube oil and seal oil.
- Seal gas supply piping.
- TEG, MEG, DEA, MEA, MDEA, DGA, AGR, and any other amine and refrigerant systems.
- If necessary to meet service fluid quality such as sales gas piping.

New and existing piping for oxygen service shall have a cleanliness level conforming to Level A (<11 mg/m^2), as described in ASTM G93.

For existing systems, **one** of the following criteria shall be used to determine when to schedule cleaning:

6.1 When the actual heat transfer coefficient (U_{actual}) drops to 60% of the (U_{design}) at heat exchanger design operating conditions.

6.2 When the drop in heat duty is unacceptable to Plant Operations.

6.3 When the flow is restricted inside the equipment or piping system due to scale build-up.

6.4 To provide access for inspection and maintenance activities.

6.5 To safely oxidize pyrophoric materials.

7 Preparations for Chemical Cleaning

7.1 The cleaning process may involve a combination of several stages based on the scale type and materials of construction of the equipment. The cleaning stages are as follows:

7.1.1 Mechanical cleaning is achieved by the use of power brushes or reamers to remove the deposits as much as possible from the equipment and piping.

7.1.2 High pressure water jetting is used to remove deposits, if access is available. See SABP-A-051 for more details.

7.1.3 Hot alkaline cleaning is used to remove oil, grease, and organic deposits and neutralize pyrophoric material with hot permanganate, alkaline treatment, surfactants, or other approved procedures.

7.1.4 Solvent cleaning is used to chemically remove mill scale, mineral deposits from water, process side deposits, and corrosion products. Also, it is used to remove tarry and polymerized deposits by cleaning with organic solvents such as heavy aromatic naphtha (HAN), kerosene, diesel, gas, oil, or any proprietary solvents.

7.1.5 Neutralization and passivation is needed to neutralize acids and to form a strongly adherent protective oxide layer on the wetted metal surface.

7.1.6 Decontamination cleaning is conducted to minimize steam out activities, clean walls, trays and packing. This is to reduce post cleaning activities, make safe vessel entry for mechanical works, repairs, and inspection, get LEL, H_2S to zero levels, get benzene to < 0.5 ppm level, and oxidize any pyrophoric materials

7.2 General Preparations

7.2.1 Install all necessary temporary piping, sacrificial valves and pressure, temperature and level instruments. Do not connect equipment with dissimilar metals into one system for circulation of acids.

7.2.2 Isolate the equipment from the process side by blinds. Install vents and adequately sized temporary valves to permit draining acids within 30 minutes. Use temporary plugs or slip blinds to isolate sections that do not require cleaning.

7.2.3 Store all chemicals needed for the procedure on-site prior to commencing cleaning, including emergency neutralizing agents and nitrogen as well as wet lay-up chemicals.

7.2.4 Ensure that an adequate supply of water is available for flushing and cleaning. Good quality water having a conductivity of less than 1,000 µS/cm.

7.2.5 Ensure that instrument connections (except those temporarily installed) are disconnected before acid cleaning stage.

7.2.6 Install fittings for liquid sampling, flow elements, temperature probes, and pipe spools with on-line access fittings for corrosion monitoring probes.

7.2.7 Provide adequate lighting at all operating points.

7.2.8 Plan for the disposal of wastewater and spent chemical solutions per SAEP-327, SAES-A-103, and SAHWC.

7.2.9 Perform checks on valve lineups as required for flushing and reversing circulation.

7.2.10 Notify the Regional Laboratories of intention to chemically clean.

7.2.11 Ensure utility water is available or provide a temporary supply connection.

7.2.12 Ensure sufficient supply of nitrogen at 80 psig (5.5 barg) to quickly drain acid cleaning chemicals from the equipment using nitrogen pressure.

7.2.13 Check and ensure that the flow design includes: flow reversal manifold and valves, control valves and bypass to control circulation within specified limits, blend filling of corrosive chemicals (acids and chelants) without exposure to the atmosphere.

7.2.14 Test the cleaning circuit hydrostatically at 1.25 times the dead head discharge pressure of the circulating pump, after installation of all temporary piping and connections, prior to chemical cleaning.

7.2.15 Ensure that an external heat source is available to maintain the cleaning fluid temperature, within the limits specified.

7.2.16 Ensure spare pumps are available in case of a pump failure to maintain circulation, and nitrogen pressure connection to drain the acid within fifteen minutes in case of an emergency. Ensure sufficient holding tank capacity is available for draining and neutralizing cleaning solutions if necessary.

7.2.17 Ensure using standard samples that on-site chemical analytical procedures and laboratory analytical procedures yield results within ±10%.

7.2.18 Ensure that inhibitor is selected to be suitable for the acid type and cleaning operation conditions.

7.2.19 Determine the volume of the equipment by filling with water and draining it through a flow meter.

7.2.20 Beware of the safety hazards (see SABP-A-051) associated with chemical cleaning and take adequate safety measures, refer to appropriate HAZCOM (see GI-0150.100).

7.2.21 Ensure that chemical feed lines are a minimum of 1/12th the diameter of the vessel or exchanger; drains and vents are clear.

7.2.22 Ensure that the chemical cleaning contractor is on-site with mixing tanks, chemicals, portable lab, flow meter, corrosion monitoring equipment (on-line probes and coupons), pH and temperature probes, and pumping equipment to blend fill and circulate chemicals.

7.2.23 Flush the equipment with water until it runs clear to remove all loose and soluble deposits.

7.2.24 Use commercial grade quality for all chemicals except where austenitic materials are present in the equipment to be cleaned. In this case, the total chlorides of all the chemicals in the mixture must not yield a final solution containing greater than 50 mg/l as free chloride.

7.2.25 Install at least one corrosion probe in the circulating loop for on-line monitoring and control of corrosion rates.

7.2.26 Install at least one corrosion coupon in the circulation loop to measure the total corrosion rate.

7.2.27 Ensure inhibitor to be used are compatible with the acid used. Test for corrosion inhibitor effectiveness prior to injecting the acid into the equipment. Refer to CSD/MED/Corrosion Engineering Group for the approved list of corrosion inhibitors.

7.2.28 For cleaning piping used in oxygen service, refer to SABP-A-072 for guidelines.

8 Cleaning Selection

8.1 General Criteria

8.1.1 Primarily select chemicals that shall be:

8.1.1.1 Safe to use

8.1.1.2 Compatible with the materials of construction (Appendix C)

8.1.1.3 Will remove > 70% of the undesired deposits

8.1.1.4 Will achieve the desired degree of cleaning.

8.1.2 With these criteria satisfied, make the final selection, with due reference to other constraints including cost, environmental restriction on disposal of waste solutions, and cleaning time available. For on-stream cleaning refer to SABP-A-051. Off-stream chemical cleaning will involve one or more of the following steps; Hot alkaline degreasing (see Section 9), acid cleaning (see Section 10), followed by neutralization and passivation treatment (see Section 11). Laboratory analyses of deposit samples will determine the need for cleaning, and cleaning steps.

8.1.3 High pressure water jetting (HPWJ) may precede or follow to remove loosened scale (see SABP-A-051). HPWJ is very effective to remove most brittle deposits. The use of HPWJ is recommended alone, before, or after chemical cleaning (prior to the passivation stage).

8.2 Analysis of Fouling Material

8.2.1 General

Fouling composition, quantity, and distribution, vary considerably between one piece of equipment and another, or even within the same equipment at various time intervals during its life. It is therefore

necessary in each case, to select a specific treatment, or series of treatments, which will be most effective in achieving thorough and safe cleaning, to restore equipment operational efficiency. Determine the composition of the scale or deposit and the suitable cleaning solution or organic solvents to remove these before any chemical cleaning.
Take representative sample or samples of the deposit.

8.2.2 Loss on Ignition

This analysis represents the weight percentage of the deposit that can be removed by heating the insoluble residue at 600°F (315°C) in a laboratory furnace. The result is indicative of the organic content of the deposit in the form of oil, grease, degraded polymers or carbon. If the figure is high (greater than 10%) further definition of the organic content can be determined by refluxing the sample with a suitable organic solvent, which will indicate the relative proportions of oil, grease, and carbon. These proportions assist in the selection of a suitable hot alkaline, permanganate treatment or decontamination cleaning.

8.2.3 Solubility in Dilute HCl

This figure represents the weight percent of the deposit, which will dissolve in boiling 7.5% wt., inhibited hydrochloric acid.

8.2.4 Insoluble Residue

This figure represents the insoluble complexes of other cations and, if the quantity is significant (i.e., greater than 2%) further treatments with more concentrated acid may be required to render the material soluble.

8.2.5 Metals

The metal ions present in the deposit, are analyzed for iron (Fe), copper (Cu), calcium (Ca), magnesium (Mg), nickel (Ni), zinc (Zn), manganese (Mn), sodium (Na), etc. These results are useful to determine the number of cleaning stages that are likely to remove all the deposits from the system.

8.2.6 Anions

Phosphate, sulfate, carbonate, and sulfide are also determined in the scale. This information is useful to determine the need for sulfate/sulfide conversion treatment or the need to suppress the evolution of H_2S during acid cleaning.

8.2.7 X-Ray Diffraction

With this technique, the crystalline identification of the scale components is made. This is useful to determine the actual composition and the insulating characteristics of the scale.

8.3 Hot Alkaline Cleaning Selection

8.3.1 Where oil, grease, carbon, or other organic compounds are present, these must be removed during cleaning. The treatment selection depends on the degree of contamination. Use hot alkaline treatment only when organic deposits interfere with acid cleaning. If the solubility of deposits is >70% in acid with or without addition of surfactants then a separate alkaline stage is not required.

8.3.2 Soda ash (Na_2CO_3) degreasing is a mild treatment used where contamination is primarily light oil and grease, with less than 5% organic contamination (see Section 9.1).

8.3.3 Caustic degreasing (NaOH) is the treatment used for all new equipment, and where mill scale is present, or organic contamination is 5% to 25% (see Section 9.2).

8.3.4 Permanganate ($KMnO_4$) degreasing is used where organic contamination is heavy (>25%) and carbonized. This treatment should only be employed if necessary, since costs, and complication of subsequent acid cleaning, are greater than the other degreasing chemicals (see Section 9.3).

8.3.5 Decontamination cleaning is used to de-oil and degrease process equipment. Moreover, decontamination can get the LEL and H_2S levels to zero and get the benzene level to less than 0.5 ppm to permit personnel entry and perform regular maintenance work (see Section 9.4).

8.4 Acid Cleaning Selection

8.4.1 Hydrochloric Acid

Inhibited hydrochloric acid is the most widely used acid since it produces good solubility with a wide variety of scales, is economic, and is easy to handle. It exhibits good corrosion characteristics when correctly inhibited and the process is controlled within the accepted limits. The process is flexible and can be modified to enhance silica removal by the addition of ammonium bifluoride, or to remove organics by addition of surfactants. However, it is not compatible with stainless steels.

8.4.2 Citric Acid

Inhibited citric acid is compatible with stainless steels, and presents good handling, safety, and corrosion characteristics. It is less aggressive in its attack of some iron oxide scales and therefore usually requires higher temperatures or longer contact times. It has little effect on calcium salts present in deposits. In general, it is more expensive than hydrochloric acid treatment. The normal reasons for its selection are: (a) the presence of austenitic materials in the materials of construction and (b) rust removal, neutralization, and passivation can be carried out using a single solution, thereby considerably reducing cleaning time by eliminating the need to drain, flush, and refill the equipment between stages.

8.4.3 EDTA

Inhibited disodium or tetra sodium EDTA salts, are used to remove calcium sulfate deposits. Corrosion rates are low under controlled conditions.

8.4.4 Sulfuric Acid

Inhibited sulfuric acid is an effective chemical for removal of iron oxides, iron sulfides and is lower in cost than hydrochloric acid. It is also compatible with stainless steels. However, it is dangerous to handle. In its concentrated form, it is aggressive to organic material, and contact with the skin or eyes are extremely dangerous. Its use is not recommended where scales contain significant calcium, due to the formation of insoluble calcium sulfate.

8.4.5 Sulfamic Acid

Inhibited sulfamic acid has the advantage of being a crystalline solid, which is simple to store, handle, and mix. It is frequently sold mixed with an inhibitor and a color indicator to show effective acid strength. It is compatible with stainless steels and is a moderately aggressive acid for iron oxide and calcium carbonate. Due to its relatively high cost, it is mainly used on small volume equipment. It is not recommended to clean copper alloys due to their susceptibility to stress corrosion cracking.

8.5 Neutralization and Passivation

Following acid cleaning it is essential that the equipment be thoroughly neutralized. This is either achieved by neutralization alone, usually with 0.5% sodium carbonate, or during the passivation treatment (see Section 10) where the process requires pH values of 7 or higher.

The selection of passivation treatment is sometimes governed by the selection of the acid. Where citric acid or EDTA processes have been used, these are extended to effect neutralization and passivation by a suitable pH adjustment and the addition of an oxidizing agent. It can also be achieved by the nitrite/phosphate treatment (see Section 11).

9 Hot Alkaline Cleaning

9.1 Alkaline Degreasing with Soda Ash (Sodium carbonate, Na_2CO_3)

9.1.1 Control Parameters

Sodium carbonate	0.5 to 1.0% by weight
Sodium metasilicate	0.5 to 1.0% by weight
Trisodium phosphate	0.5 to 1.0% by weight
Surfactant	0.1 to 0.2% by volume
Anti-foam (if required)	0.05 to 0.1% by volume
Temperature limits	167 – 185°F (75 – 85°C)
Circulation rate	1 to 2 volumes / hour
Residence time	6 to 12 hours

9.1.2 Testing

Determine every hour the cleaning solution phosphate and M-alkalinity values. If the M-alkalinity and phosphate concentrations have dropped to half the original values, add chemicals to restore the original concentration.

9.1.3 Safety Hazards

The solution can react violently with acids. Heating the solution will expand its volume. Be prepared to open drain valves to maintain desired levels.

9.1.4 Procedure

1. Verify volume of equipment to appropriate level by filling and draining through a flow meter.
2. Dissolve the chemicals externally and blend fill through the chemical feed connection. Open vent and fill the equipment from the bottom to ensure adequate contact of degreasing solution with the contaminated metal surfaces.
3. Provide external heating to control temperature.

4. Circulate for 6 to 12 hours reversing flow every 30 minutes. However, the end point of the degreasing process shall be governed by the analysis results and not by the residence time set in Section 9.1.
5. Drain the solution quickly with air pressure (5 psig / 0.35 barg max) into a holding tank.
6. Fill the equipment with water heated to 170°F (77°C) and drain quickly to rinse.
7. Inspect the equipment.
8. If no further cleaning is required, then reconnect all instrument lines.
9. Replace all hand and manhole covers, using new gaskets.
10. Remove blinds, temporary piping, and instruments.
11. Place the equipment in service.

9.2 Caustic Degreasing (Sodium hydroxide, NaOH)

9.2.1 Control Parameters

Sodium hydroxide	1.0 to 2.0% by weight
Trisodium phosphate	0.5 to 1.0% by weight
Surfactant	0.1 to 0.3% by volume
Anti-foam (if required)	0.05 to 0.1% by volume
Temperature limits	167 – 185°F (75 – 85°C)
Circulation rate	1 to 2 volumes/hour
Residence time	6 to 12 hours

9.2.2 Testing

Determine every hour the phosphate and M-alkalinity values. If the M-alkalinity and phosphate concentrations have dropped to half the original values, add chemicals to restore the original concentration.

9.2.3 Safety Hazards

Sodium hydroxide reacts exothermically with water. Therefore, never add water to it. Add sodium hydroxide, either liquid or solid, into water slowly with constant stirring. Heating the solution will expand its volume. Be prepared to open drain valves to maintain desired levels.

9.2.4 Procedure

The procedure is same as in Section 9.1.4.

9.3 Permanganate Treatment (Potassium Permanganate, $KMnO_4$)

This procedure is good for degreasing and also to convert pyrophoric iron sulfides to soluble sulfates and to eliminate H_2S liberation if HCl is used subsequently.

9.3.1 Control Parameters

Sodium hydroxide	1.0 to 3.0% by weight
Potassium permanganate	1.0 to 3.0% by weight
Temperature limits	167 – 185°F (75 – 85°C)
Circulation rate	1 to 2 volumes/hour
Residence time	6 to 12 hours

9.3.2 Testing

Take samples at one-hour intervals. Monitor the cleaning solution M-alkalinity, permanganate concentration, and temperature. If the permanganate strength drops below 1.0%, do not add permanganate to increase its concentration. Drain the equipment into a holding tank, add fresh degreasing solution, and continue circulation.

9.3.3 Safety Hazards

Handle potassium permanganate carefully as it is a strong oxidizing agent. Add slowly add with constant stirring to dilute sodium hydroxide in water.

9.3.4 Precautions

Do not use any antifoam or surfactant as these will react with permanganate and deplete its strength. This treatment frequently results in the deposition of manganese dioxide. If this treatment is to be followed by hydrochloric acid stage, chlorine may be liberated with a consequent increase in corrosion rates and safety hazards.

Commentary Note:

> *Where a permanganate treatment is used, the residual scale will probably be contaminated with manganese dioxide. This will liberate chlorine in contact with hydrochloric acid and 1.0% of oxalic acid must be added to the hydrochloric acid to prevent this. The liberation of chlorine gas in the*

low pH HCl environment will result in accelerated corrosion in the form of severe pitting attack.

9.3.5 Procedure

1. Verify volume of equipment to appropriate level by filling and draining through a flow meter.
2. Dissolve the chemicals externally and blend through the chemical feed connection. Open the vent and fill the equipment from the bottom to ensure adequate contact of the cleaning solution with the contaminated metal surfaces.
3. Provide heat externally to bring to desired temperature range.
4. Circulate for 6 to 12 hours reversing flow every 30 minutes. Monitor until the permanganate concentration stabilizes.
5. Drain the solution quickly under air pressure (5 psig / 0.35 barg max) into a holding tank.
6. Fill the equipment with water heated to 170°F (77°C) and drain quickly to rinse.
7. Inspect the equipment.
8. If no further cleaning is required then reconnect all instrument lines.
9. Replace all hand and manhole covers, using new gaskets.
10. Remove blinds, temporary piping, and instruments.
11. Place the equipment in service.

9.4 Decontamination Cleaning

The decontamination procedure circulates a non-corrosive, hot (175 – 195°F / 80 – 90°C) water/chemical solution through the system. Decontamination cleaning minimizes steam-out activities, cleans walls, trays and packing to reduce post cleaning activities, makes safe vessel entry for mechanical works, repairs and inspection, gets LEL and H_2S to zero levels, gets benzene to < 0.5 ppm level, and oxidizes any pyrophoric materials.

9.4.1 Control Parameters

Decontamination chemical	2 to 5% by volume
Temperature limits	175 – 195°F (80 – 90°C)
Circulation rate	1 to 2 volumes/hour
Residence time	12 to 24 hours

9.4.2 Testing

Take samples at one-hour intervals. Monitor the hydrocarbon concentration, decontamination chemical concentration, and temperature.

9.4.3 Safety Hazards

In general, decontamination chemicals are safe to handle; however, a standard safety practices shall be observed. Moreover, most decontamination chemicals are biodegradable and they can be discharged to the industrial sewers with water. For every decontamination product, consult the MSDS of the product for more information.

9.4.4 Procedure

1. Filling Water into the System
    - i. Line up water to the suction of the temporary contractor’s pump
    - ii. Line up the circulating flow loop from discharge of contractor’s pump
    - iii. Pump water into the system
    - iv. Add water to the required level
2. Hot Water Circulation
    - i. Increase temperature of circulating water to 80 – 90ºC by using steam
    - ii. Start to circulate the hot water using contractor’s pump
    - iii. Pump out all water to the sewer drain point
3. Chemical Addition
    - i. Refill the system with soft water or condensate
    - ii. Continue to circulate adding steam to the system to raise the temperature to 175 – 195°F (80 – 90°C).
    - iii. Test circulating water for hydrocarbon content. If the hydrocarbon content is greater than 10%, then the system shall be completely or partially drained to achieve the target.
    - iv. Add the decontamination chemicals to the circulating systems.
    - v. Maintain temperature between to 175 – 195°F (80 – 90°C).
    - vi. Draw samples and test hydrocarbon content.

vii. The contractor will notify operations when the hydrocarbon content stabilizes.

viii. The contractor will request plant operation to divert the gas out from blow down to the atmosphere or to the flare line.

4. Draining

    i. When hydrocarbon level stabilizes, stop pumping.

    ii. Pump all the emulsion out.

    iii. Stop pump once the system is empty.

    iv. If Iron Sulfide (FeS) is present, then a permanganate solution wash, or any equivalent chemical, shall be performed to oxidize any pyrophoric materials.

5. Rinsing

    i. Line up raw water to the system.

    ii. Start circulation into the system.

    iii. Rinse the system.

    iv. Stop pump after 2 hours of circulation.

    v. Drain the system and low point drains to the plant drainage system if it is acceptable with the plant or to contractor's fracture tanks.

9.4.5 Inspection

i. Open the system and perform gas testing.

ii. Inspect the internal surfaces. Surfaces shall be free of any hydrocarbons.

10 Acid Cleaning

10.1 General

Following removal of organic material, acid cleaning is carried out to remove iron oxides, sulfides, water borne scales, copper or silica. The acids are selected as noted in Section 8.

Although the acid concentrations listed encompass most cleaning operations, some times higher acid, inhibitor and ammonium bifluoride concentrations may be beneficial. Extended contact times may be required than those specified for removing certain heavy and hard to remove deposits. Changes to the specified procedures below require prior approval from CSD/MED/Corrosion Engineering Group.

Commercial grade quality for all listed chemicals is adequate. The concentrated acid must not contain greater than 100 mg/l of iron. Where austenitic materials are present in the system to be cleaned, the total chlorides of all the chemicals in the mixture must not yield a final solution containing more than 50 mg/l as chloride.

Perform a hydrostatic pressure test of the cleaning circuit at 1.25 times the dead head pressure of the circulating pump before acid addition.

10.2 Hydrochloric Acid (HCl)

10.2.1 Do not use this procedure in equipment and piping with mixed metallurgy or with stainless steel. More than one acid cleaning cycle may be required to remove all scales.

10.2.2 Control Parameters

Hydrochloric acid	3.5 to 7.5% by weight
Inhibitor	0.2 to 0.3 % by volume or as recommended by manufacturer
Surfactant	0.0 to 0.2% by volume
Ammonium bifluoride	0.0 to 1.0% by weight
Oxalic acid	1.0% by weight
Temperature limits	140 – 162°F (60 – 72°C)
Circulation rate	1 to 2 volumes/hour
Residence time	6 to 10 hours
Max. corrosion rates	< 600 mpy
Total dissolved Iron	10,000 mg/L max.

10.2.3 Testing

Prior to commencement, test the inhibitor for effectiveness using the steel wool test or any other testing method. During circulation, monitor the solution for acid strength, total iron concentration, corrosion rate, temperature, and inhibitor effectiveness. Take samples at 30 minute intervals, or more frequently. Perform analyses as rapidly as possible and preferably on-site.

10.2.4 Safety Hazards

Hydrochloric acid is a strong mineral acid. Handle with suitable precautions, particularly in the concentrated state. Oxalic acid is highly toxic.

10.2.5 Precautions

Review materials of construction to ensure that they are compatible with high chloride solutions. Austenitic stainless steels are prone to stress corrosion cracking in such environments and must not be present in systems to be cleaned by hydrochloric acid. Do not use HCl to clean equipment and piping with ferrous and nonferrous metals that are not electrically isolated. Corrosion rates are controlled by a number of variables. These include temperature, circulation rate, residence time, acid concentration, inhibitor concentration, and concentration of dissolved ions. Control these variables within their limits unless approved by CSD/MED/Corrosion Engineering Group.

10.2.6 Procedure

1. Replace all permanent valves, which will come in contact with acid, with sacrificial valves or protect them with blinds. If sacrificial valves are not available, keep new valves on hand for replacing all valves contacted by acid during the cleaning procedure.

2. Monitor the real time corrosion rate using an on-line corrosion probe.

3. Fill the equipment from the bottom with water to the top eliminating all air in the system. If the water is sufficiently hot, circulate by chemical cleaning pumps to achieve uniform metal temperatures throughout the equipment, and adjust to 140 – 162°F (60 – 72°C). If the water is not at a high enough temperature, use an external heat exchanger, or inject steam, to raise and adjust temperature by circulation.

4. Strip dissolved oxygen in the inhibited acid by sparging nitrogen at 1 m^3/hr using a PVC pipe into the acid containers for at least 1 hour.

5. Use nitrogen to drain back sufficient volume of water to accommodate inhibited acid addition. Check the inhibitor effectiveness in the acid on-site. As quickly as possible, blend fill the equipment with inhibited acid solution. Blend a slightly higher concentration during the beginning of the fill than at the end because the initial acid entering the equipment is consumed to some degree during the fill. Ammonium bifluoride may be added

in concentrations up to 1.0% by weight to assist in the removal of silica. In the absence of silica, the ammonium bifluoride concentration shall not exceed 0.5% by weight when it is added to assist in the removal of iron.

6. Circulate solution using chemical cleaning pumps. Reverse the flow direction every 30 minutes using flow reversal manifold. Take samples from the various locations and monitor temperature, acid strength, iron concentration, and inhibitor effectiveness.

   During circulation, temperatures will gradually decay from 162°F (72°C). This is acceptable down to 140°F (60°C). If it becomes necessary to raise the temperature, use an external heat exchanger. Do not inject steam into the acid solution. If the acid strength falls below 3.0%, or if the total iron exceeds 10,000 mg/l, drain the equipment immediately into a holding tank under nitrogen pressure of 10 psig (0.7 barg) and go to step 2.

7. Continue circulation, taking test samples every 30 minutes. Continue cleaning until the acid solution and total iron concentration approach equilibrium. Note that the end point of the acid process shall be governed by the analysis results and not by the residence time set in Section 10.2.2.

8. Check for acid leaks in the circulation system, and if the leaks cannot be contained, drain as in step 9.

9. Drain the acid into a holding tank under a positive nitrogen pressure of 10 psig (0.7 barg). Drain as fast as possible, using the maximum number of drain valves consistent with maintaining a positive nitrogen pressure. Introduce nitrogen into the equipment through the vent line.

10. Fill to the top of the equipment with hot water mixed with 2 to 3% of soda ash. Drain the equipment under nitrogen as before and refill with water, for a second rinse. Drain the second rinse under a positive nitrogen pressure. Soda ash may have to be added to the solution drained directly into the sewer, to ensure that its pH is about 7. When no repeat acid cleaning is required, about 0.1% by weight of citric acid should be added to the second rinse to assure more thorough rust removal.

11. If the acid is drained because of any one of the three reasons cited in step 6 or 8 above, water flush to clear drains and repeat the procedure from step 3.

10.3 Citric Acid ($C_6H_8O_7$)

10.3.1 More than one acid cleaning cycle may be required to remove all the rust when citric acid is used. Citric acid is not as effective as hydrochloric acid to remove water scales or iron sulfides.

10.3.2 Control Parameters

Iron Removal Phase	
Citric acid	2.5 to 5% by weight
Inhibitor	0.2 to 0.3 % by volume or as recommended by manufacturer
Ammonia or sodium hydroxide	To adjust the pH 4.0 to 4.5 Ammonia is not compatible with copper or copper alloy
Passivation Phase	
Ammonia or sodium hydroxide	pH 9.0 to 9.5
Sodium nitrite	0.5% by weight
Temperature Limit	
Iron removal phase	149 – 167°F (65 – 75°C)
Passivation phase	113 – 122°F (45 – 50°C)
Residence Time	
Iron removal phase	4 to 8 hours
Passivation phase	4 to 8 hours
Total dissolved Iron	10,000 mg/L max.
Circulation rate	1,200 liters/minute to 4,500 liters/minute
Max. corrosion rates	< 600 mpy

10.3.3 Testing

Take samples at 30 minute intervals. During rust removal, monitor the corrosion rate, temperature, iron concentration, free citric acid concentration, and pH.

10.3.4 Safety Hazards

Handle sodium nitrite carefully as it is a strong oxidizing agent.

10.3.5 Precautions

Corrosion rates are controlled by a number of variables. These include temperature, circulation velocity, residence time, acid concentration and concentration of dissolved ions. Control these variables within their limits unless approved by CSD/MED/Corrosion Engineering Group.

10.3.6 Procedure

1. Fill the equipment from the bottom with water to the top eliminating all air in the system. If the water is sufficiently hot, circulate by chemical cleaning pumps to achieve uniform metal temperatures throughout the equipment, and adjust to 167°F (75°C). If the water is not at a high enough temperature, use an external heat exchanger or inject steam to raise and adjust temperature by circulation.
2. Monitor the real time corrosion rate using an on-line corrosion probe.
3. Use nitrogen to drain back sufficient volume of water to accommodate inhibited acid addition. Check the inhibitor effectiveness in the acid on-site. As quickly as possible, blend fill the equipment with premixed inhibited citric acid with sufficient amount of ammonia or sodium hydroxide to adjust pH to 4.0 to 4.5.
4. Circulate solution using chemical cleaning pumps. Reverse flow direction every 30 minutes using flow reversal manifold. Take a sample and monitor the temperature, free citric acid strength, iron concentration, inhibitor effectiveness, and pH. If the free citric acid strength falls below 1.0%, add citric acid to maintain 1.0% level. During circulation, temperatures will gradually decay from the original levels. The temperature drop to 149°F (65°C) is acceptable at the completion of this phase. However, if it becomes necessary to raise the temperature, use an external heat exchanger. Do not inject steam into the acid solution.
5. Continue circulation, taking test samples every 30 minutes, and until the acid solution and total iron concentration approach equilibrium. Note that the end point of the acid process shall be governed by the analysis results and not by the residence time set in Section 10.3.2.
6. Check for acid leaks in the circulation system. If the leaks cannot be contained, or if the total iron exceeds 10,000 mg/l, drain the equipment immediately into a holding tank under nitrogen pressure of 10 psig (0.7 barg), rinse the equipment with water, water flush to clear drains, and repeat the procedure from step 1.

7. Ensure free citric acid concentration is 1.0%. If not, add further citric acid to achieve this level in order to prevent precipitation of iron. Add or sodium hydroxide or ammonia to adjust pH to 9.5.
8. Add 0.5% sodium nitrite. Continue circulation for a minimum of 2 hours.
9. Drain under air and fill the equipment with hot water to the top. Drain the equipment under air as before and refill with water, for a second rinse. At this point the equipment is both neutralized and passivated.

10.4 EDTA Salt

Use this procedure to remove sulfate deposits.

10.4.1 Control Parameters

Tetra or disodium EDTA	3 to 10.0% by weight for sulfate removal
Inhibitor	0.2 to 0.3 % by volume or as recommended by manufacturer
pH	> 9.5
Temperature limits	176 – 203°F (80 – 95°C)
Circulation rate	1 to 2 volumes/hour
Residence time	6 to 12 hours
Max. corrosion rates	< 50 mpy

10.4.2 Testing

Prior to commencement, test the inhibitor for effectiveness. Take samples every 30 minutes. Monitor the pH, EDTA concentration, corrosion rate, and the temperature.

10.4.3 Procedure

1. Fill the equipment with hot water, then inject concentrated premixed solution of EDTA with inhibitor to provide a 10.0% solution in the equipment.
2. Monitor the real time corrosion rate using an on-line corrosion probe.
3. Do not allow the temperature to decay below 176°F (80°C). Monitor the EDTA concentration and pH. Maintain the pH above 9.5 by adding caustic if necessary. If the free EDTA

concentration drops below 1.0%, inject more EDTA to restore concentration to 3.0%-10%.

4. Drain the solution with air pressure into a holding tank. Fill and drain twice with water.
5. Open the equipment and inspect. Use hydrojetting to remove loose sulfate deposits if any.

10.5 Sulfuric Acid (H_2SO_4)

More than one acid cleaning cycle may be required to remove all the rust when using sulfamic acid solution. Do not use H_2SO_4 to clean exchangers with ferrous and nonferrous metals that are not electrically isolated.

10.5.1 Control Parameters

Sulfuric acid	4.0 to 8.0% by weight
Inhibitor	0.2 to 0.3 % by volume or as recommended by manufacturer
Surfactant	0.0 to 0.2% by volume
Temperature limits	149 – 167°F (65 – 75°C)
Circulation rate	1 to 2 volumes/hour
Total residence time	6 to 10 hours
Max. corrosion rates	< 600 mpy
Dissolved Iron	10,000 mg/L max.

10.5.2 Testing

Prior to commencement, test the inhibitor for effectiveness.
During circulation monitor the solution for acid strength, the total iron concentration, corrosion rate, temperature, and inhibitor effectiveness. Take samples at 30 minute intervals. Perform analyses as rapidly as possible and preferably on-site.

10.5.3 Safety Hazards

Sulfuric acid is a strong mineral acid, and must be handled with care, particularly in the concentrated form. Considerable heat is evolved during dilution. Never add water to concentrated sulfuric acid.
Add the acid slowly to water while mixing thoroughly.

10.5.4 Precautions

Corrosion rates are controlled by a number of variables. These include inhibitor concentration, temperature, circulation velocity, residence time, acid concentration, and concentration of dissolved ions. Control these variables within their limits unless approved by CSD/MED/Corrosion Engineering Group.

10.5.5 Procedure

1. Replace all permanent valves, which will come in contact with acid, with sacrificial valves. If sacrificial valves are not available, keep new valves on hand for replacing all valves contacted by acid during the cleaning procedure.
2. Fill the equipment from the bottom with water to the top eliminating all air in the system. If the water is sufficiently hot, circulate by chemical cleaning pumps to achieve uniform metal temperatures throughout the equipment, and adjust to 167°F (75°C).

   If the water is not at a high enough temperature, use an external heat exchanger, or inject steam, to raise and adjust temperature by circulation.
3. Strip dissolved oxygen in the inhibited acid by sparging nitrogen at 1 m^3/hr using a PVC pipe into the acid containers for at least 1 hour.
4. Use nitrogen to drain back sufficient volume of water to accommodate inhibited acid addition. Check the inhibitor effectiveness of the acid on-site. Blend fill the equipment with the inhibited acid solution as quickly as possible. Blend a slightly higher concentration during the beginning of the fill than at the end because the initial acid entering the equipment is consumed to some degree during the fill.
5. Circulate the solution using chemical cleaning pumps. Reverse the flow direction every 30 minutes using flow reversal manifold. Take samples and monitor the temperature, acid strength, iron concentration, and inhibitor effectiveness. During circulation, temperatures will gradually decay from the original figure of approximately 167°F (75°C). This is acceptable to 149°F (65°C). If it becomes necessary to raise the temperature, use an external heat exchanger. Do not inject steam into the acid solution. If the acid strength falls below 3.0%, or if the total iron exceeds 10,000 mg/l, drain the equipment immediately into a holding tank under nitrogen pressure of 10 psig (0.7 barg) and go to step 2.
6. Continue circulation, taking test samples every 30 minutes.

Continue cleaning until the acid concentration and total iron concentration approach equilibrium. Note that the end point of the acid process shall be governed by the analysis results and not by the residence time set in Section 10.5.1.

7. Monitor the real time corrosion rate using an on-line corrosion probe.
8. Drain the acid into a holding tank under a positive nitrogen pressure of 10 psig (0.7 barg). Drain in as short a time as possible, using the maximum number of drain valves consistent with maintaining a positive nitrogen pressure. Introduce nitrogen into the equipment through the drum vent line.
9. Fill the equipment with hot water mixed with 2 to 3% of soda ash to the top. Drain the equipment under nitrogen as before and refill with water, for a second rinse. Drain the second rinse under a positive nitrogen pressure. Soda ash may have to be added to the solution drained directly into the sewer, to ensure that its pH is above 7. When no repeat acid cleaning is required about 0.1% by weight of citric acid should be added to the second rinse to assure more thorough rust removal.

10.6 Sulfamic Acid (H_3NSO_3)

More than one acid cycle may be required to clean. Do not use sulfamic acid to clean exchangers with copper alloys due to possibility of stress corrosion cracking. Approximately 1 kg of sulfamic acid will dissolve 0.5 kg of $CaCO_3$.

10.6.1 Control Parameters

Sulfamic acid	5.0 to 10.0% by weight
NaCl*	2.5% by weight
Inhibitor	0.1 to 0.2 % by volume or as recommended by manufacturer
Surfactant	0.0 to 0.2% by volume
Temperature limits	131 – 149°F (55 – 65°C)
Circulation rate	1 to 2 volumes/hour
pH	< 1.5
Residence time	6 to 10 hours
Max. corrosion rates	< 600 mpy **
Total dissolved Iron	10,000 mg/L max.

* Add to enhance rust removal only in carbon steel systems

** For stainless material, corrosion rate < 200 mpy

10.6.2 Testing

Prior to commencement, test the acid for inhibitor effectiveness. Take samples at 30 minute intervals, or more frequently. Perform analyses as rapidly as possible and preferably on-site. Monitor the acid strength and iron concentrations, corrosion rate, temperature and the inhibitor effectiveness.

10.6.3 Precautions

Corrosion rates are controlled by a number of variables. These include temperature, circulation velocity, residence time, concentration of acid, inhibitor concentration, and dissolved ions. Control these variables within their limits unless approved by CSD/MED/Corrosion Engineering Group.

10.6.4 Procedure

1. Fill the equipment from the bottom with water to the top eliminating all air in the system. If the water is sufficiently hot, circulate by chemical cleaning pumps to achieve uniform metal temperatures throughout the equipment, and adjust to 149°F (65°C).

   If the water is not at a high enough temperature, use an external heat exchanger, or inject steam, to raise and adjust temperature by circulation. Use nitrogen to drain back sufficient volume of water to accommodate inhibited acid. Check the inhibitor effectiveness in the acid on-site. Blend inhibited acid solution into the equipment as quickly as possible. Blend a slightly higher concentration during the beginning of the fill than at the end because the initial acid entering the equipment is consumed to some degree during the fill.

2. Circulate the solution using chemical cleaning pumps. Reverse the flow direction every 30 minutes using flow reversal manifold. This is essential in order to achieve good cleaning, reduce corrosion, and maintain uniform temperatures and concentrations. Take samples, and monitor temperature, acid strength, iron concentration, and inhibitor effectiveness. During circulation, temperatures will gradually decay. This is acceptable to 131°F (55°C). If it becomes necessary to raise the temperature, use an external heat exchanger. Do not inject steam into the acid solution. Check for leaks in the circulation system. If the leaks cannot be contained or, if the acid strength falls below 1.0%, or pH raises above 1.5, or if the total iron exceeds 10,000 mg/l, drain

the equipment immediately into a holding tank under nitrogen pressure of 10 psig (0.7 barg) and go to step 1.

3. Continue circulation, taking test samples every 30 minutes. Continue cleaning until the acid concentration and total iron concentration approach equilibrium. Note that the end point of the acid process shall be governed by the analysis results and not by the residence time set in Section 10.6.1.
4. Monitor the real time corrosion rate using an on-line corrosion probe.
5. Drain the acid under a positive nitrogen pressure of 10 psig (0.7 barg) into a holding tank. Drain in as short a time as possible, using the maximum number of drain valves consistent with maintaining a positive nitrogen pressure. Introduce nitrogen into the equipment through the vent line.
6. Fill the equipment from the bottom with water to the top. Drain the equipment under nitrogen as before and refill with water, for a second rinse. Drain the second rinse under a positive nitrogen pressure. Soda ash may have to be added to the solution drained directly into the sewer, to ensure that its pH is above 7. When no repeat acid cleaning is required about 0.1% by weight of citric acid should be added to the second rinse to assure more thorough rust removal.

11 Neutralization and Passivation

11.1 General

Immediately after cleaning with mineral acids and rinsing of the equipment, the final step is passivation of the freshly cleaned steel surfaces. Passivation is not required for equipment made of non-ferrous alloys or stainless steels.
Use commercial grade quality for listed chemicals except where austenitic materials are present in the system to be cleaned, the total chlorides of all the chemicals in the mixture must not yield a final solution containing greater than 50 mg/L as chloride.

11.2 Inspection

Following the neutralization step, visually inspect equipment to determine whether another acid stage or high pressure water jetting is required.
Also, inspect following the high pressure water jetting to determine its effectiveness in removing the scale and if more jetting is required before moving to the passivation stage.

11.3 Control Parameters

Sodium nitrite ($NaNO_2$)	0.5% by weight
Monosodium phosphate	0.25% by weight
Disodium phosphate	0.25% by weight
Sodium hydroxide	Adjust pH to 7
Temperature limits	122 – 149°F (50 – 65°C)
Circulation rate	1 to 2 volumes / hour
Residence time	4 to 6 hours
Max. corrosion rates	< 2 mpy

11.4 Testing

Monitor and maintain pH by adding caustic if necessary.

11.5 Safety hazards

Sodium nitrite is a strong oxidizing agent and it must be handled with extreme care.

11.6 Procedure

1. Fill the equipment to the top with passivation solution, and circulate by chemical cleaning pumps.
2. Continue circulating for 6 hours while maintaining the temperature.
3. At the end of the six hours, drain the equipment under air pressure.
4. Open vents, drain, and inspect internals for completion of work.
5. The passivated surface must have a thin gray color (blackish) iron oxide (magnetite) film.

12 Evaluating Cleaning Performance

Plant Inspection and the cleaning contractor shall inspect the system after the cleaning, to ascertain that the job has been successfully completed. Visual and video boroscope inspections are carried out to determine the effectiveness of cleaning. No visible traces of water, or deposits (loose or adherent) inside the equipment are acceptable.
For oxygen service, follow Section 8 of SABP-A-072.

13 Equipment Lay-Up

If the startup of the equipment after cleaning is likely to be delayed by more than five days, dry it with nitrogen to a dew point of 30°F (-1°C) or less and store it under a positive pressure of nitrogen of 5 psig (0.35 barg) for corrosion protection.

Revision Summary

23 August 2011	Revised the "Next Planned Update". Reaffirmed the contents of the document, and reissued with minor changes.
28 October 2013	Minor revision.
30 September 2014	Major revision.
16 October 2016	Major revision to clarify and address gaps identified by the Standard Committee members. Those gaps are outlined below: a) Include all relevant equipment and piping systems; b) Include all related Saudi Aramco and International References; c) Align Testing Requirements with International Standards NACE TM 0169, NACE TM 0193 and ASTM G93; d) Include New Section on Roles and Responsibilities; e) Include New Section on Definitions and Abbreviations; f) Clarify Criteria for Cleaning and Cleaning Performance; and g) Relocate All Non-Mandatory Requirements to New SABP-A-051.

Appendix A - Contractor Submittals

Submittals for review and approval shall include the following:

1 Equipment and Piping Details

- Location, fill volume, materials of construction of shell and tubes or plates and gaskets
- Components isolated, blinded, plugged, or removed
- Scale composition and solubility in the proposed solvent

2 Selected Treatments for Cleaning

- High pressure water jetting
- Hot alkaline treatment
- Acid treatment
- Passivation

3 Materials and Quantities

- Water volume for each stage of cleaning
- Nitrogen volume for each stage of cleaning
- Chemicals and quantities
- Inhibitor name and quantity

4 Equipment and Piping Details

- Pumps and capacities
- Piping, fittings, and valves
- Tanks and capacities
- Power source

5 Control Parameters

- Circulation rate, temperature limits, chemical concentrations, pH, M-alkalinity, iron, corrosion

- Sketch of circulation path, showing locations of: pumps, control valves, chemical injection, flow and temperature instruments, vents, drains, blinds, plugs, etc.
- Waste disposal plan and approvals per SAEP-327, SAES-A-103, and SAHWC.
- Chemical analysis procedures
- Contractor safety manual
- Contingency plans to handle piping leaks, pump failures, rescue from confined spaces
- Corrosion control methodology
- Quality assurance and control procedures
- Personnel assigned and their qualifications
- Schedule of activities, start, and end dates

6 Final Report

The contractor shall submit a final report to include the approved cleaning procedure, all control parameters, log sheets, evaluating cleaning performance by Inspection, and lessons learned, etc.

7 Safety

- Job safety analysis document
- Material Safety Data Sheets (MSDS) for the cleaning chemicals

Appendix B - Chemical Cleaning Log Sheet

Plant Location		Chemicals Used	
Equipment No.		Date / Time Started	
Equipment Type		Date / Time Finished	

Date	Time	Solvent Temp (°F/°C)	Acid %	Total Iron (mg/l)	pH	PO_4^{3-} / CO_3^{2-} mg/l	Corrosion Rate (mpy)	Remarks

Appendix C - Cleaning Chemical Compatibility Chart for Materials*

Inhibited Chemicals	Metal Group							
	Carbon Steel C-Mo steel Cr-Mo steel	**Cast iron**	**Stainless steels Alloy 20 (N08020) Alloy 600 (N06600) Alloy 800 (N08800) Alloy C-276 (N10276)**	**Nickel Alloy 400 (N04400) Alloy B-2 (N10665)**	**Copper-base alloys CuNi alloys**	**Aluminum alloys Zinc alloys Galvanized steel**	**Titanium**	**Tantalum**
Hydrochloric (HCl) * Add ammonium bifluoride to enhance cleaning and remove Silica (e) (add formaldehyde to remove Hydrogen Sulfide) (Limit circulation to 0 3 – 0 6 m/s)	Compatible, A	**C, α**	**NR**	**β**	Compatible, A	**NR**	**C, χ**	Compatible, A
Sulfuric (H_2SO_4) * (Hazardous to handle) (Limit circulation to 1 5 m/s)	Compatible, A	Compatible, C	Compatible , C	Compatible, A	Compatible, A	**NR**	**C**	Compatible, A
Phosphoric (H_3PO_4) * (Limit circulation to 1 5 m/s)	Compatible, A	**NR**	Compatible, A (a)	Compatible, A	Compatible, A	**NR**	**NR**	Compatible, A
Sulfamic (H_2NO_3S) (a) * (Limit circulation to 1 5 m/s)	Compatible, A	**C**	**C**	Compatible, A	Compatible, A (d)	**A**	**C, ##**	Compatible, A
Nitric/Hydrofluoric (HNO_3)/(HF) (c) * **(Toxic)** (Limit circulation to 0 3 – 0 6 m/s)	**NR**	**NR**	Compatible, A (a)	**NR**	**NR**	**NR**	Compatible, A	**NR**
Citric ($C_6H_6O_7$) (b) ** (Limit circulation to 1 5 m/s)	Compatible, A	Compatible, A	**C**	Compatible, A	**C**	Compatible, A	Compatible, A	Compatible, A
Ammonium Citrate ($NH_4C_6H_7O_7$) (b) **	Compatible, A	Compatible, A	Compatible, A	Compatible, A	**NR**	**NR**	Compatible, A	Compatible, A
Hydroxyacetic / Formic ($C_2H_4O_3$)/(CH_2O_2)** (Limit circulation to 1 m/s)	Compatible, A	**NR**	Compatible, A	Compatible, A	Compatible, A	**NR**	Compatible, A	Compatible, A
Ammonium EDTA($NH_4C_{10}H_{15}O_8N_2$) (b) (Limit circulation to 1 5 m/s)	Compatible, A	C	Compatible, A	Compatible, A	**C, Φ**	C	Compatible, A	Compatible, A
Sodium Hydroxide ($NaOH$) (Caustic)	α	Compatible, A	α	Compatible, A	Compatible, A	**NR**	Compatible, A	α
Potassium Permanganate ($KMnO_4$) (e) (Effective against sulfides and hydrogen sulfides (H_2S))	Compatible, A	Compatible, A	Compatible, A	Compatible, A	Compatible, A	**NR**	Compatible, A	Compatible, A

Inhibited Chemicals	Metal Group							
	Carbon Steel C-Mo steel Cr-Mo steel	**Cast iron**	**Stainless steels Alloy 20 (N08020) Alloy 600 (N06600) Alloy 800 (N08800) Alloy C-276 (N10276)**	**Nickel Alloy 400 (N04400) Alloy B-2 (N10665)**	**Copper-base alloys CuNi alloys**	**Aluminum alloys Zinc alloys Galvanized steel**	**Titanium**	**Tantalum**
Limitations	A = Acceptable under normal range of concentration and temperature described in the Guide. Acid must contain metal corrosion inhibitor. Corrosion should be monitored to assure that equipment being cleaned is not exposed to high corrosion rates							
	C = Acceptable only under certain conditions or precautions. Some corrosion may occur even under ideal conditions.							
	NR = Not recommended. Other solvents or cleaning methods should be used.							
	α = Observe concentration and temperature limits (Temp. < 50°C)							
	β = No ferric or cupric ions allowed - special inhibitor required							
	χ = Only when ferric or cupric ions are present							
	(a) = Except Ferritic and martensitic stainless steels							
	(b) = Inhibitor required with metal groups 1 and 2, and with Ferritic and martensitic stainless steels							
	(c) = Only for passivation (pickling) previously cleaned surfaces							
	(d) = Do not exceed 45° C to prevent decomposition to sulfuric acid and ammonia							
	(e) = Ambient temperature only (exothermic reaction, should be continually cooled if necessary)							
	(f) = Copper ↔ NO Ammonia							
	(∞) = Aluminum ↔ NO high pH solution							
	TEG ↔ NO acid or any oxidizing agent (Explosion)							
	## = No Fluorides and T<=60°C							
	*Inorganic (mineral) Acid Note: Sulfuric acid can be used to clean refractory				**Organic Acid	Φ Sodium EDTA can be used for copper-based allow		

*Use this table as a reference only