MANUAL

CLEANING OF EQUIPMENT

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DESIGN AND ENGINEERING PRACTICE

PREFACE

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Shell International Oil Products B.V. (SIOP)
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Shell International Exploration and Production B.V. (SIEP)
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Shell International Chemicals B.V. (SIC)

The Hague, The Netherlands,

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They are based on the experience acquired during their involvement with the design, construction, operation and maintenance of processing units and facilities, and they are supplemented with the experience of Group Operating companies. Where appropriate they are based on, or reference is made to, national and international standards and codes of practice.

The objective is to set the recommended standard for good design and engineering practice applied by Group companies operating an oil refinery, gas handling installation, chemical plant, oil and gas production facility, or any other such facility, and thereby to achieve maximum technical and economic benefit from standardization.

The information set forth in these publications is provided to users for their consideration and decision to implement. This is of particular importance where DEPs may not cover every requirement or diversity of condition at each locality. The system of DEPs is expected to be sufficiently flexible to allow individual operating companies to adapt the information set forth in DEPs to their own environment and requirements.

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NOTE: In addition to DEP publications there are Standard Specifications and Draft DEPs for Development (DDDs). DDDs generally introduce new procedures or techniques that will probably need updating as further experience develops during their use. The above requirements for distribution and use of DEPs are also applicable to Standard Specifications and DDDs. Standard Specifications and DDDs will gradually be replaced by DEPs.

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APPENDICES

1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for chemical and mechanical cleaning methods for the removal of fouling deposits, including practical cleaning methods for various types of equipment, and a brief description of sludge removal from crude oil storage tanks.

This DEP is a revision of the DEP of the same number dated September 1992.

Excluded from the scope of this DEP is the cleaning or drying of transmission pipelines.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIOP and SIEP, the distribution of this DEP is confined to companies forming part of the Royal Dutch/Shell Group or managed by a Group company, and to Contractors nominated by them (i.e. the distribution code is "C", as defined in DEP 00.00.05.05-Gen.).

This DEP is intended for use in oil refineries, supply/marketing installations, chemical plants, gas plants, and, where applicable, in exploration and production facilities.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the object of obtaining agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project, or operation or maintenance of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced by this DEP are listed in (8).

2. FOULING

Inorganic scales, corrosion products, dirt, sand, organic growth and organic sediments are all common sources of fouling.

Fouling deposits range from very tenacious scales to thick layers of deposits of varying hardness. These layers are categorised as general fouling when contaminants in the form of small suspended particles are deposited on the surface. The settling rate is directly proportional to particle size and inversely proportional to liquid viscosity and density. These deposits are normally soft and easy to remove; a common form of general fouling is sludge.

Scaling is generally caused by precipitation of solids (salts) out of soloution onto heat exchange surfaces, due to high concentrations or increased temperature. Scaling can also be caused by sulphide or oxide layers formed by high temperature corrosion.

Fouling has a negative effect on the performance of equipment. The type and content of fouling or deposit formation is related to the process or type of equipment. Common signs of fouling are flow reduction, increased pressure drop, reduced heat transfer or under deposit corrosion. Visual inspection, radiography or thermography may also indicate the extent of fouling.

Although equipment may be designed to minimise fouling, the possibility of fouling can never be entirely eliminated. Chemical and mechanical cleaning methods will normally be required and the necessary provisions should be made.

Fouling deposits can be divided into several types:

2.1 INORGANIC DEPOSITS

These can form in heat transfer equipment (usually on the cooling water side), inside boiler tubes and on external surfaces of boiler and furnace tubes. These scales/deposits may be formed by combustion of fuels, by corrosion of the equipment or, in heat transfer equipment, by precipitation from the water stream or process stream at elevated temperatures. The deposits mainly consist of one or more of the following components:

- carbonates, oxides or hydroxides of calcium, magnesium, iron, manganese, copper and zinc;
- phosphates of calcium, magnesium and iron;
- sulphides of iron, copper, zinc and ammonium;
- sulphates of calcium;
- chlorides of calcium, magnesium, ammonium and sodium;
- vanadium pentoxide;
- silica/silicates;
- fluorides.

2.2 ORGANIC DEPOSITS

Organic fouling formed by biological growth such as slime, algae, shellfish, jellyfish and barnacles are encountered in cooling water circuits. On the process side of equipment, organic deposits (varying from light hydrocarbons to heavy polymers) and coke may be found, depending on the composition and temperature of the process stream.

2.3 MIXED INORGANIC/ORGANIC DEPOSITS

A mixture of inorganic/organic fouling is sometimes encountered in water circuits, when hydrocarbons and/or chemical products leak from the process side.

2.4 POLYTHIONIC ACID STRESS CORROSION CRACKING

CAUTION:

In H_2S service, a neutralisation procedure shall be applied prior to opening any equipment containing austenitic stainless steel components (e.g. HDS reactors) in order to protect against polythionic acid stress corrosion cracking. Details of the procedure can be found in NACE RP0170.

3. CHEMICAL CLEANING

3.1 GENERAL

Chemical cleaning is the process of removing fouling deposits with chemical solutions. The cleaning action may be entirely chemical, using acids or caustics, but may also be assisted by physical means using solvents, steam or hot water.

Cleaning operations shall be conducted in such a way that they will not lead to unacceptable pollution of the environment.

Most inorganic deposits can be removed by using acids or acid-based commercial cleaning agents, while alkaline solutions can be used for the removal of some organic deposits. Mixtures of cleaning solutions, such as high-aromatic solvents (excluding benzene) with an emulsifying agent, may remove some tar and polymer deposits.

To determine the most suitable cleaning agent for a particular application, a representative sample of the fouling deposit shall be investigated in a laboratory. The envisaged cleaning agent and corrosion inhibitor shall be tested on the sample at the same temperature that will be used for the actual cleaning process. If sample deposits cannot be obtained then the experience of the contractor and/or other Shell Operating Units should be requested.

Cleaning procedures should be available before plant or equipment is shut down and based on deposit samples taken on some previous occasion. The procedure and frequency of cleaning should be noted in a "plant cleaning manual" or similar document and should be reviewed periodically to identify areas of improvement.

For equipment that cannot be moved and for systems of vessels and piping, etc., chemical cleaning can be carried out in situ, using mobile facilities to circulate cleaning agents through the equipment.

Chemical cleaning can also be carried out by immersion of equipment in a cleaning agent. This is suitable for small parts or for equipment containing deposits difficult to remove in situ, such as plugged heat exchangers. The immersion procedure should be carried out in a central cleaning yard. Sometimes an additional cleaning method, such as high pressure (HP) water jetting, is required after immersion.

On-stream chemical cleaning should be applied only after careful consideration since process temperatures may not be suitable and contamination by the cleaning agent could occur throughout the system (see 3.4.7 and 3.4.8).

Chemical cleaning should be carried out by specialised contractors unless the Principal has sufficiently experienced labour. Before a contract is awarded, adequate arrangements shall be made for neutralisation and environmentally acceptable disposal of used cleaning agents. The Contractor’s equipment and procedures shall be approved by the Principal before the work starts. The Principal’s focal point shall monitor that the work is carried out in accordance with the approved procedure, that all safety precautions are taken and that used cleaning agents are disposed of in an environmentally acceptable way.

Before starting any unproven chemical cleaning activity, the following basic rules shall be complied with (see 3.6.1):

- a corrosion test shall be carried out on an inhibited acid sample, using test coupons of the metals of the equipment or systems to be cleaned. Some fouling deposit shall also be added as this may influence the attack on the test strips;
- to monitor corrosion, coupons or probes should be installed in the equipment or system prior to the cleaning activity;
- the equipment shall be inspected before and after cleaning to check the effectiveness of the cleaning operation and to look for signs of metal attack (welds may be more vulnerable);
- prior to the introduction of chemicals, a hydrostatic test of the entire system should be performed at the system design test pressure to check for leakage. This shall be repeated after all cleaning operations are completed.

3.2 SURFACTANTS

Surfactant solutions are becoming more widely used to improve the effectiveness and reduce the time needed for equipment decontamination during process unit shutdowns. The primary objective of the decontamination phase of a shutdown is the removal of hazardous materials from vessels, piping, and auxiliary equipment. However, surfactants can also effectively clean refinery equipment by eliminating residual bulk hydrocarbons, as well as hydrocarbon films and sludges.

Typically, commercially available surfactants specifically designed for the petrochemical industry are mixed with circulating hot water at a temperature of between 80 °C and 90 °C. A surfactant concentration of between 1% and 2% is usually employed depending on the nature of the hydrocarbon to be removed. The surfactant causes an emulsion to form between the hydrocarbon and the water phases. The emulsion is removed to a holding tank where the emulsion is broken, usually adding a salt solution; typically calcium chloride. The hydrocarbon phase can then be recovered and processed. The water phase is usually removed through the site water treating facilities.

Experience has shown that surfactant cleaning can reduce the time required during shutdowns by 50% or more. The time saved and the resultant increase in plant availability can often more than offset the costs of surfactant cleaning. Details of some experience can be found in articles 10, 11 and 12 of the SIOP Maintenance and Inspection Bulletin, 16th edition (December 1996).

3.3 ADVANTAGES AND LIMITATIONS OF CHEMICAL CLEANING

When compared with mechanical cleaning, chemical cleaning has advantages and limitations as follows:

The advantages of chemical cleaning are:

- cleaning can often be carried out without dismantling the equipment;
- cleaning is more effective since all parts (assuming no blockages) will be reached, resulting in more uniform cleaning;
- when carried out by competent personnel, the damage caused by chemical cleaning is generally less than that due to conventional mechanical cleaning. Any damage induced by conventional mechanical cleaning could enhance corrosion and/or fouling during subsequent operation.

The limitations of chemical cleaning are:

- chemically inert material, e.g. coke deposits, cannot be removed;
- severely fouled or fully plugged equipment will require mechanical cleaning since the circulation of cleaning agents would be impossible, or so limited as to render chemical cleaning ineffective;
- corrosion rates of materials during chemical cleaning are generally low, but severe damage may still occur if improper procedures are applied, e.g. stress corrosion cracking of stainless steel induced by chlorides, stress corrosion cracking of carbon steel (and other metals) caused by hydrogen sulphide released during chemical cleaning, caustic embrittlement of carbon steel and risk of hydrogen induced cracking (HIC)/blistering because sulphide-containing scale is present;
- safe and environmentally acceptable disposal of cleaning agents is required after neutralisation;
- emissions released during cleaning may have to be treated to protect all personnel in the area as well as the environment.

Combination of chemical and mechanical cleaning:

- In some cases where tenacious deposits such as residues are present chemical cleaning using surfactants, followed by mechanical cleaning (H.P water jetting), may be the most effective.

3.4 CLEANING AGENTS

For chemical/physical cleaning a selection should be made from the following agents:

Note: Oil and grease shall be removed prior to any acid cleaning to ensure that the acids come into contact with the deposits. An alkaline wash is recommended.

3.4.1 Hydrochloric acid

This acid is mostly used in cleaning because it is relatively cheap and usually readily available. It effectively removes many inorganic deposits containing e.g. carbonates and iron sulphide. Because it is very corrosive towards most metals, effective inhibitors shall be used which will reduce corrosion without affecting the cleaning action.

Hydrochloric acid is typically applied in a concentration of 2% to 5% by weight and at temperatures up to a maximum of 65 °C. When cleaning by circulation, the velocity shall be restricted to 0.5 m/s, because at higher velocities the efficiency of the inhibitor will be reduced. The ferric ion concentration shall be kept below 0.4% by weight to avoid severe corrosion, and a minimum circulation rate of 0.2 m/s is required to ensure deposits are removed.

Ammonium bifluoride (typically 1% by weight) added to hydrochloric acid is often used to remove SiO_2 (silica). For the removal of scale the acid shall be added in a controlled manner, because the reaction between scale and acid will release gases and heat.

If calcium sulphate and silicate deposits are to be removed an alkaline boil-out may also be required prior to acid cleaning (see Appendix 1).

Restrictions on the use of hydrochloric acid for cleaning are:

- if the ferric ion concentration exceeds 0.4% by weight, some acid should be dumped and fresh acid solution added to restore acid concentration;
- hydrochloric acid shall not be used for cleaning austenitic stainless steel, e.g. AISI 304, 321,347, 316, 310, to avoid pitting and/or chloride stress corrosion cracking. Parts made of these materials, such as thermowells or valve internals, shall be removed from the cleaning circuit;
- care should be exercised when heating hydrochloric acid solutions because the acid is highly volatile, and the vapour is toxic and corrosive.
- for cleaning aluminium brass bundles, even inhibited hydrochloric acid may cause general attack. The cleaning frequency and the cleaning conditions shall be restricted. The liquid shall not be reused for cleaning steel equipment (see 3.6.1).

3.4.2 Sulphuric acid

Sulphuric acid is less versatile than hydrochloric acid, but is often used when chloride stress corrosion cracking could otherwise occur. It can form insoluble salts, e.g. with calcium. Effective inhibitors shall be used to prevent corrosion of the metallic parts.

Sulphuric acid should be applied in concentrations of 4% to 10% by weight and at temperatures up to a maximum of 75 °C. When cleaning by circulation, the velocity shall be restricted to 0.5 m/s and the ferric ion concentration shall be kept below 0.4% by weight.

Ammonium bifluoride (typically 1% by weight) added to sulphuric acid is used to remove silica.

3.4.3 Citric acid

Citric acid is available in crystals. It is applied for the removal of millscale in new boilers and delicate equipment such as turbine rotors. Although corrosion rates are low, effective inhibitors shall be used.

Citric acid is typically applied in concentrations of 5% to 6% by weight and cleaning temperatures up to 95 °C can be used to reduce cleaning time. Citric acid can also be used to remove copper (see Appendix 1).

Citric acid is suitable for many materials and should be used when austenitic stainless steel parts are present.

For cleaning equipment with internals made of 12% chromium steels (e.g. type AISI 405, 410, 410S) citric acid shall be used only at temperatures below 60 °C.

3.4.4 Sulphamic acid

Sulphamic acid is also a crystalline acid, but its use should be carefully considered due to some known cases of severe pitting corrosion.

3.4.5 Alkaline solutions

Alkaline solutions are used when an alkaline boil-out is applied prior to acid cleaning of boilers (see Appendix 1).

3.4.6 Aromatic solvents

Aromatic solvents may be used for the removal of some tar and polymer products. They should be mixed with an emulsifying agent.

NOTE: Benzene shall not be used as a solvent.

3.4.7 Ethylene diamine tetra-acetic acid

The tetra-sodium salt of ethylene diamine tetra-acetic acid (EDTA) has been used for on-stream cleaning of boilers. Its continuous use is not recommended because unless it is correctly injected and controlled, severe corrosion will occur.

3.4.8 Chelating agents

Chelating agents specifically formulated for the on-stream cleaning of boilers are commercially available.

On-stream cleaning using such chemicals can have the advantage of potentially restoring efficiency without having to shut down the boiler to carry out a conventional chemical clean.

The on-stream cleaning approach has to be very carefully evaluated as the chemicals employed can be very costly and their effectiveness may not always match the suppliers' claims. As with EDTA, their use has to be very carefully controlled.

3.5 INHIBITORS

When acids are used for chemical cleaning, metals will be severely attacked unless a suitable inhibitor is added. The effectiveness of inhibitors is affected by acid velocities, which should normally be restricted to 0.5 m/s. There is also a temperature limit above which the inhibitor will decompose and lose its effect. For this reason inhibited acid solutions shall not be heated with live steam.

Several types of inhibitor are commercially available, such as Rodine and Armohib (for which chemical cleaning contractors may use their own type description). Manufacturers' prescriptions shall be closely followed for the particular application since the inhibitor is only suitable for one type of acid and metal, and some inhibitors give optimum performance only when added to the concentrated acid.

The effectiveness of a proposed inhibitor shall be checked by exposing metal test coupons to the inhibited acid solution (see 3.6).

During the actual cleaning process the continued effectiveness of the selected inhibitor should be checked by immersing a sample of the construction material (e.g. steel wool in the case of carbon steel) in the cleaning solution. After dispersal of air bubbles, the inhibitor is considered effective if no gas bubbles are formed.

3.6 EFFECTS OF CLEANING AGENTS ON CONSTRUCTION MATERIALS

3.6.1 General

Cleaning agents selected for the type of fouling deposit shall also be checked for any unfavourable effect they may have on all the construction materials of the equipment. Acids and alkaline solutions may cause high corrosion rates or other adverse effects; therefore, before starting a cleaning application, a careful laboratory investigation is required in cases where no comparable experience is available.

The testing procedure shall be as follows:

Test coupons of materials similar to the construction materials of the equipment to be cleaned shall be exposed to the cleaning agent for 24 hours. The concentration and temperature of the cleaning agent shall be as intended for the actual cleaning. The inhibitor shall be added to the cleaning agent.

A sample of the fouling deposit shall also be added, since this may influence the attack on the test strips. It also allows the cleaning efficiency to be tested.

In order to obtain the effect of velocity during actual cleaning, the sample should be stirred continuously.

From the weight loss of the test coupons the corrosion rate can be determined, which should be not more than 0.01 mm in 24 hours. Any tendency towards pitting shall also be observed. The inhibitor will need to be replaced and the test repeated until an acceptable rate is found.

Table 3.6 may be used as a guide. Sections 3.3 and 3.4 give further limitations.

Chemical cleaning should not last too long, as some attack will always occur. Different materials may also be affected at differing rates, e.g. with 12-Cr steel internals in a carbon steel column, the inhibitor should be adequate to protect both the carbon steel and the 12-Cr steel.

Table 3.6 Suitability of chemical cleaning agents

	Concentration (% wt)	Maximum temperature °C	Carbon steel and low alloy steels	Cast iron	12-Cr steel	Austenitic stainless steel	Cu/Ni	Aluminium	Monel	Aluminium brass
Inhibited hydrochloric acid	2-5	65	**+**	**+**	**x** **	**-**	**x**	**-**	**-**	**-**
Inhibited citric acid	6	95	**+**	**+**	**x** *	**+**	**+**	**x**	**+**	**+**
Inhibited sulphuric acid	4-10	75	**+**	**+**	+	**+**	**+**	**-**	**+**	**-**
Alkaline solutions		70	**+**	**+**	+	**+**	**+**	**-**	**+**	**x**
Organic solvents			**+**	**+**	+	**+**	**+**	**+**	**+**	**-**

x = restricted

+ = generally suitable

- = unsuitable

* = 60 °C maximum, (see 3.3.3)

** = Ambient temperature only, (see 5.2.1)

3.6.2 Effects on special materials

Chemical cleaning of special materials mentioned in (3.6.2.1 through 3.6.2.5) shall be considered on a case-by-case basis.

3.6.2.1 Tantalum

Tantalum equipment shall not be cleaned with acids or alkaline solutions. Acids may cause embrittlement due to absorption of the released hydrogen, and alkaline solutions will cause serious corrosion.

3.6.2.2 Titanium and silver

Any type of cleaning of titanium and silver or silver-lined equipment which causes disturbance of the initially formed protective film shall be avoided, since serious corrosion may occur.

3.6.2.3 Glass lining

Glass-lined equipment shall not be cleaned with alkaline solutions and its steel jackets shall not be cleaned with acids, for reasons mentioned in 3.6.2.4.

3.6.2.4 Coatings and linings

For certain coatings and linings, acid cleaning of the uncoated side shall not be performed. The hydrogen gas formed may penetrate through the steel wall and cause loosening and/or spalling of the coating or lining, e.g. acid cleaning shall not be used on the shell side of heat exchangers having a baked-on coating on the tube side.

3.6.2.5 Graphite

Graphite equipment shall not be cleaned with oxidising chemicals or with cleaning solutions containing phenolic or cresolic compounds.

3.7 METHODS, EQUIPMENT AND FACILITIES FOR CHEMICAL CLEANING

3.7.1 General

The cleaning method to be applied depends on the type and size of equipment, type and amount of fouling deposits, available cleaning facilities and safety aspects. Outlined below are the basic procedures for acid cleaning in situ by circulation and by immersion.

Practical methods for cleaning various types of equipment are given in Section 5. Detailed procedures for the cleaning of boilers, both inside the tubes and on the flue gas side, are included in Appendix 1 and Appendix 2.

3.7.2 Acid cleaning in situ by circulation

The following procedure applies in general:

- the system to be cleaned should be filled with potable water and a hydrostatic test carried out to check for leakage;
- circulation should be started (if necessary, via a heater);
- sufficient water should be drained to allow the dosage of inhibitor and acid. The Manufacturer's instructions shall be followed as to whether the inhibitor should be dosed to the water or to the acid;

  NOTE: As an alternative the cleaning agent may first be prepared at the required concentration in a mobile unit.

- acid should gradually be introduced while circulating at a limited velocity of 0.5 m/s maximum;
- during cleaning, regular checks of the acid concentration shall be made (see also Appendix 1). Samples shall be taken regularly to monitor cleaning progress: e.g. iron breakthrough indicates that deposits are being removed; calcium levels become constant during the removal of calcium carbonate scale. These are indications that the cleaning process has to be stopped, as further circulation could result in corrosion of the materials being cleaned. The effectiveness of the inhibitor is important at this stage. The Manufacturer and contractor performing the work must provide guidelines.
- the acid solution shall be drained into a tank, neutralised to pH 7 (± pH 1) and removed from site.
- the system should be flushed with water on a once-through basis;
- the metal surface shall then be neutralised with a 1% to 2% solution of sodium carbonate circulated at ambient temperature;
- if the equipment is not immediately required for service, a passivated surface shall be provided for which purpose alkaline solutions containing sodium nitrite may be used. Time for neutralising/passivating treatment shall be sufficient to allow the neutralisation of acid in less accessible areas, e.g. gasket faces. A hydrostatic test should be carried out before recommissioning the equipment.

3.7.3 Cleaning by immersion

Chemical cleaning by immersion should be carried out in a central cleaning yard.

The advantages of a central cleaning yard are:

- it is safer;
- there is no interference with other activities;
- it reduces pollution problems;
- additional mechanical cleaning can be performed more conveniently.

Three immersion tanks should be installed to conserve cleaning agents; at least one tank should be provided with a heating coil. The original component is then neutralised and

washed.

Facilities for the storage and/or supply of cleaning agents, air, steam, water and electricity are required as well as proper facilities for the disposal of spent cleaning solutions, neutralising agents and the safe and environmentally acceptable release of toxic gases.

Reference should be made to (4.4.3) for facilities required for HP water jetting if this is also to be carried out in the central cleaning yard.

3.8 SAFETY AND ENVIRONMENTAL PROTECTION

Before starting any chemical cleaning operation, adequate measures for safety and protection of the environment shall be established. All local regulations shall be complied with and the Principal's requirements shall be observed.

The cleaning area shall be closed off to unauthorised personnel.

Warning signs shall be posted to forbid smoking, welding, flame cutting and unauthorised entering of the cleaning area.

Cleaning agents, inhibitors and chemicals shall be transported in closed containers, drums or tanks.

Where necessary, adequate drip pans shall be placed underneath the equipment to avoid soil contamination (either by oil or cleaning liquid). Disposal of liquid leakage should follow the same procedure as for bulk liquids.

Protective clothing shall be worn and other protective equipment (face shields, special gloves) shall be used during cleaning and when handling cleaning agents.

An emergency shower with eye bath shall be available to wash away splashed hazardous chemicals.

During cleaning with acid, adequate venting shall be provided to prevent the accumulation of any explosive gas mixture; special measures (ventilation) shall be taken to vent isolated pockets in a safe manner.

Dilution of acid shall always be effected by slowly adding the concentrated acid to water, stirring to avoid splashing and to prevent the temperature from rising above 75 °C. When cleaning austenitic stainless steel, demineralised or condensed water shall be used for dilution purposes.

Arrangements shall be made for the safe and environmentally acceptable disposal of used cleaning agents via a neutralisation unit or disposal tank. Direct disposal to a sewer may be performed only after neutralisation and on confirmation of environmental acceptability. If the disposal tank contains organic cleaning materials or contaminants, biotreatment shall be applied.

Ammonium bifluoride is a toxic substance and appropriate precautions shall be taken (when handling concentrated solutions, face masks, rubber gloves and leggings are advised).

Arrangements shall be made for the safe disposal of gases released during cleaning, including toxic gases such as hydrogen sulphide and sulphur dioxide.

During chemical cleaning of equipment containing sulphurous compounds such as iron sulphide, hydrogen sulphide will be released and strict precautions shall be taken. Refer to the Shell Safety and Health Committee Publication "Hydrogen sulphide". The gases formed during the chemical cleaning process should be routed to a caustic absorption pot to absorb the released hydrogen sulphide. The discharge from the pot shall be routed to a safe location for venting. The discharge from the vent shall be carefully monitored to detect hydrogen sulphide breakthrough so that the caustic charge in the absorption pot can be replenished. After the chemical cleaning or whilst changing the caustic inventory of the absorber pot it must be assumed that hydrogen sulphide is still present, possibly at a slight overpressure. Therefore, replenishing or removal of the caustic pot must be done with great care, taking hydrogen sulphide precautions such as:

- purging the vapour space of the vessels included in the acid cleaning circuit, via the pot to atmosphere;
- performing a gas test for hydrogen sulphide when removing the caustic pot;
- use of breathing apparatus when removing the caustic pot.

During acid cleaning, agitation with air shall not be performed as this may result in the formation of explosive hydrogen-oxygen mixtures. Agitation with nitrogen may be applied.

The presence of mercury is possible, particularly when processing hydrocarbon condensate

from gas fields. Mercury traps are used to prevent contamination of process unit equipment.

The release of mercury and its compounds to the environment shall be prevented.

Vanadium oxides and other metal compounds (e.g. nickel and molybdenum) may be present on the fire side of furnaces/boilers and are dangerous to health. Protective breathing apparatus shall be used during cleaning of such equipment.

4. MECHANICAL/PHYSICAL CLEANING

4.1 CONVENTIONAL METHODS

Scraping, brushing, drilling or blasting with abrasives are conventional mechanical cleaning methods in which the cleaning effect is obtained by abrading away the deposits.

In using any of these methods great care shall be taken not to damage the equipment being cleaned.

Brushing can be applied for the removal of relatively soft deposits. For the cleaning of the inside of heat exchanger tubes, special cleaning brushes with extension rod assemblies are available. Care shall be taken to avoid mechanical damage to the tubes due to bending of the extension rods.

Drilling and turbining of exchangers and furnace tubes is no longer common practice, having largely been replaced by high-pressure water jetting or hydraulic pigging.

4.2 STEAM CLEANING

When fouling deposits have to be removed by spraying with a mixture of steam and water or with a cleaning agent, the Hydro-steam cleaner can be used.

It is a mobile device in which steam and a cleaning agent are mixed in an injector; the solution is then sprayed onto the fouled equipment via a hose and a spray gun. The temperature and the flow rate of the solution are controlled by the pressure and quantity of the steam and cleaning agent. Steam at a pressure of 3 bar (ga) to 10 bar (ga) will be required.

NOTE: Additional relief valves may be required to protect commercial steam cleaners.

The unit should be suitable for the external cleaning of most plant equipment, e.g. finned air coolers, tanks, aluminium sheeting etc.

NOTE: Cleaning activity can result in hydrocarbon release; suitable precautions shall be taken.

4.3 SHOT JET CLEANING

Shot jet cleaning is similar to conventional shot-blasting, using round steel shot propelled by a high-velocity gas stream, usually nitrogen, into the open end of the pipe to be cleaned. The kinetic energy of the shot dislodges deposits and sweeps away built-up film. The shot/deposit mixture is exhausted down the pipe as it is cleaned; spray water should be used to suppress dust.

The major difference between shot jet cleaning and conventional blasting is the angle of incidence of the abrasive particles. With conventional blasting, the abrasive strikes the surface perpendicularly, whereas in shot jet cleaning the controlled flow of abrasive shot impinges on the pipe surface at a low angle of incidence.

This method may be applied for the removal of non-ductile coke from the inside of furnace tubes up to 150 mm diameter, preferably without variations in the diameter. It is also suitable for the removal of inorganic deposits, and, since its application is independent of the tube material, it has advantages over steam-air decoking. Satisfactory results have been obtained in removing deposit from the inside of air cooler tubes, using air at a pressure of 6 bar (ga) instead of nitrogen. Shot jet cleaning should be carried out only by contractors with suitable experience.

NOTE: Nitrogen is an inert gas and can cause asphyxiation. Hence suitable personnel protection measures shall be taken. Refer to the Shell Safety and Health Committee Publication "Asphyxiation - the hidden danger".

4.4 HIGH-PRESSURE WATER JET CLEANING

4.4.1 General

HP water jet cleaning is the most common method of conventional mechanical cleaning for many purposes. It is also often used to complete a chemical cleaning process.

The water jet impinges on the deposits, breaks through to the underlying metal and lifts off the debris. To obtain optimum results, adequate water pressure and water flow shall be established for each cleaning operation.

Units with a capacity of 130 litres of water per minute and a pump pressure of 1 000 bar (ga) maximum are still used, mainly for the cleaning of heat exchanger tubes. However, effective cleaning of other types of equipment and of piping with hard deposits requires higher water pressures and delivery rates. Cleaning action can be further enhanced by the use of cavitation heads or abrasive entrainment.

Units with a range of 130 l/min of water at 1 000 bar (ga) to 430 l/min at 375 bar (ga) are now frequently used. Although higher water pressures and delivery rates will result in more effective cleaning, the use of manually operated pistols is limited by the maximum allowable reaction force of 250 N (or, when working in enclosed spaces, 150 N). For HP water jet cleaning, operators shall be adequately trained, protective clothing shall be worn and safe procedures shall be adopted. For the safe use of HP water jetting equipment, reference is made to (4.4.4). The reaction forces and other data for various nozzles are given in Appendix 5.

4.4.1.1 Ultra high pressure (UHP) water jetting

It is now possible to attain pressures as high as 2 700 bar with flow rates of about 16 l/min. Such systems are remotely operated and track mounted using rigid lances. UHP water jetting can be very useful for cleaning heat exchanger bundles with extremely hard deposits and or blockages. This has been successfully employed in the removal of deposits in exchangers in furfural and sulphur (caked) service. A very high standard of cleaning can be achieved, suitable for the “IRIS” method of inspection.

Details of some experience can be found in article 7 of the SIOP Maintenance and Inspection Bulletin, 16th edition (December 1996).

4.4.2 Cleaning in situ

4.4.2.1 Mobile unit

HP water jetting should be carried out in an enclosed area of the central cleaning yard. However, if equipment to be cleaned cannot be moved, in-situ cleaning may be performed if suitable precautions are taken. For this purpose, mobile units containing a skid-mounted high-pressure pump and its driver should be used, complete with high-pressure hoses, foot valves and a variety of lances and nozzles. Steps shall be taken to ensure safe and environmentally acceptable disposal of effluent. If necessary, plant equipment in the vicinity shall be adequately protected from the spray.

4.4.2.2 Rotary tank cleaning head

For internal cleaning of vessels, reactors, columns, etc. the rotary tank cleaning head should be used with the mobile unit above. This device can successfully remove rubber deposits inside reactors, and columns can be cleaned without removing trays. As far as possible, personnel should not enter such units during the cleaning operation.

The cleaning heads are available in 3 designs:

operating pressure	-	30 to 400 bar (ga)
flow rate	-	40 to 400 l/min
rotor speed	-	1 to 20 revolutions per minute

The head is provided with 2 rotors, actuated by the reaction forces of an offset rotor. The nozzles can be brought closer to the wall by using extension tubes, 200 mm to 800 mm long or 1 500 mm long. The cleaning head can be used in the following different ways:

- suspended on a flexible hose;
- suspended on a cable with the water supply from below;
- mounted on a tube in any position.

4.4.3 Cleaning in a central yard

If a large number of heat exchanger tube bundles are to be cleaned, the purchase of semi-automatic equipment may be considered. The use of this equipment, when compared to manual cleaning, will result in:

- safer conditions;
- more effective cleaning;
- significant saving in cleaning time;
- less pollution of plants and surroundings.

A description is given below of an existing set up used to chemically/mechanically clean 500 heat exchanger tube bundles per year.

The equipment is installed in a central cleaning yard and consists of:

- an adequate sewer system provided with facilities for the neutralisation of waste water and a central collection pit. The waste water should be sent to a treatment unit;
- 4 storage vessels for chemicals;
- 1 overhead crane, capacity 15 t, 10 m reach;
- 3 immersion basins, 7 m x 2 m x 2 m, for soaking;
- 2 immersion basins, 10 m x 3 m x 3 m, for soaking;
- 2 enclosed areas for cleaning bundles with HP water by means of manually operated pistols, equipped with rollers for rotating the bundles;
- 1 bundle blaster for external cleaning of tube bundles;
- 2 tube lancing machines for internal cleaning of tube bundles;
- 3 high pressure pumps, each of capacity 150 litres of water per minute at 700 bar.

The "bundle blaster" is located in a roofless enclosure of concrete walls, height 3 metres. The blasting unit consists of a rail-mounted operating cabin which can be moved alongside the tube bundle. Projecting from the closed cabin is a transport beam along which a small traveller, with a holder provided with six nozzles, can be moved forwards or backwards, while the nozzle holder can be turned in any direction. From the jet-proof cabin a single operator can carry out all cleaning operations by hydraulic motor control.

The tube lancing machines are located in a roofless enclosure of part steel and concrete walls. The operating cabin is rail-mounted and attached to it is a table provided with 6 lances. For plugged tube bundles, a special drilling table provided with 3 drills can also be attached. A single operator can carry out all the necessary cleaning operations from within the jet-proof cabin by hydraulic motor control.

Experience has shown that the bundle blaster can effectively clean the majority of tube bundles without the need for chemical pre-cleaning. Only severely fouled bundles, e.g. those that have been in short residue, asphalt and rubber service require soaking in a cleaning agent to soften the deposit before blasting.

NOTES:
1. During the shutting down procedure it may be beneficial to flush out heat exchangers in heavy hydrocarbon service using gas oil or selected solvents. In this way the use of immersion baths may be eliminated (see 5.3.4).

2. A high capital investment was involved in the installation of the equipment described above. Based on the above, facilities should be selected to suit the specific requirements of the location concerned, e.g. a single bundle blaster, etc.

3. Some contractors offer units with 12 lances.

4.4.4 Safe use of high-pressure water jetting equipment

Local regulations will determine the level at which the term high-pressure (entailing certain restrictions or special procedures) is applicable; generally, this is 10 bar (ga). In the absence of such regulations the following general principles shall be observed.

Each location shall provide procedures for the safe use of high-pressure water jetting equipment by its personnel. Such procedures shall include as a minimum any of the following items that may be appropriate to the specific operating conditions.

- Movable equipment should be cleaned in a permanent cleaning bay, enclosed by walls on three sides, height approximately 3 m.
- The cleaning operation should only be carried out in situ when items of equipment cannot be moved.
- The area of operations shall be clearly defined by substantial barriers. Warning notices shall be prominently displayed at all approaches to the area, prohibiting entrance of unauthorised personnel.
- When working on an open grating, the floor shall be suitably covered to prevent hazard to anyone below. If water can flow in an uncontrolled way to the floor beneath, the lower area shall also be fenced off and warning notices posted accordingly. The floor of the operating area shall afford a firm foothold for operators.
- Any equipment underneath the working platform shall be properly protected to avoid ingress of water into insulation or contamination of stainless steel materials.
- In some instances toxic chemicals may be included in the waste water e.g. polycyclic aromatics (PCAs). The plant operations personnel shall notify the cleaning personnel of the potential dangers and the protective measures to be taken.
- Operatives of the jetting equipment should be thoroughly trained in its use and the hazards involved. Individual training records should be available, and the training should be approved, for example, by an Association of High Pressure Water Jetting Contractors or equivalent.
- The equipment to be used shall be free from all leaks and the fail safe cut off devices (foot pedal or hand operated device and gun trigger) must be in proper working order.
- The equipment should be electrically earthed.
- There should be a minimum of two equipment operators, in visual contact: one man for the fail safe cut off device and one for the lance or nozzle. Agreed hand signals should be used.
- Personal protective clothing should comprise a PVC suit, safety footwear, safety helmet and face visor, PVC gloves and hearing protection. When working inside vessels a safety harness and lifeline should be used.
- The working area shall be effectively roped off and warning signs shall be posted. If scaffolding is required then it shall be positioned to give a safe working position.
- If a forward-moving nozzle is used instead of a lance, the length of the metal nozzle shall be greater than the diameter of the pipe to be cleaned. This is to prevent the nozzle from doubling back. The hose shall be marked such that the operator can see when the nozzle is close to the entry point. If the nozzle is less than 500 mm inside the pipe, the unit shall not be under pressure.
- The workers, supervisors and Company permit-to-work signatories should be familiar with the possible medical consequences of an accident in which penetration of the body by the water jet may have occurred. This information should be available at the work site and should also be given to the physician treating the case.

4.5 INDUCED WAVE TECHNOLOGIES

The techniques included in this category are based on inducing waves (ultrasonic, acoustic or shock waves) or pressure pulses in order to achieve cleaning. Their application is currently limited to the cleaning of the inner surface of fouled tubes in heat exchangers, boilers and piping systems.

These techniques are not widely known or used in the Group and they are currently being evaluated. Two techniques currently under investigation are:

(a) Hydrokinetic cleaning, entailing the delivery of a water stream from a pump to the tube being cleaned, through an orifice and using a set of valves to create a shock wave (pulse) travelling through the tubes;

(b) Discharge impulse technology, based on the generation of shock waves inside the tubes

through the use of an electro-hydraulic source.

Both techniques are suitable for in-situ cleaning, claiming less water consumption and more safety than high pressure hydrojetting. The former method has been commercially available since 1993 in the USA, patented by AIMMTech. The company Smet Jet is the licencee for Belgium, the Netherlands and Germany. Discharge impulse technology has been used in Russia for many years, but has not been tested in W. Europe so far.

Other techniques, including the simultaneous application of chemical cleaning and ultrasonics to give shorter cleaning times, are also under investigation.

4.6 SPONGEJET CLEANING

SpongeJet is a modern technique which employs commercial abrasives embedded in particulate polyurethane sponge to clean and, if required, profile surfaces. A range of abrasive grades is available allowing for a high degree of surface cleanliness (up to Sa 3). On impact of the abrasive with the substrate, the sponge draws dust and debris into the cell structure and absorbs the inertial energy associated with blasting, thus giving rise to a safer, cleaner blasting procedure.

Experience has shown that SpongeJetting is a viable alternative to open grit blasting and power/hand tool cleaning in a range of applications. Although not directly competitive with open grit blasting, unless special environmental, safety or operational factors are involved, it has proved to be a cost-effective blasting tool in many situations. In particular SpongeJet has been shown to be both technically and economically advantageous when blasting in shut downs and for maintenance painting or cleaning in operational environments, especially in the vicinity of sensitive equipment. When used instead of mechanical cleaning it is both faster and yields a higher quality surface finish, which in turn generates substantial savings in maintenance costs over paint lifetimes. Experiences with the SpongeJet Surface preparation technique have been reviewed in report OP 97.20188.

5. PRACTICAL CLEANING METHODS

5.1 GENERAL

This section deals with cleaning methods applicable to the following types of refinery equipment:

- columns, vessels, reactors;
- shell-and-tube heat exchangers in general service, HF service and luboil service;
- boilers on the steam/water side and on the flue gas side;
- furnace tubes;
- piping systems.

As the composition and effectiveness of commercial cleaning agents will differ from one location to another, no preferences are given.

The information provided in this section is intended to give guidance to staff who are less familiar with cleaning operations.

5.2 CLEANING OF COLUMNS, VESSELS, REACTORS

Cleaning can be carried out in situ by the circulation of cleaning agents.

Although complete filling with liquid may not be necessary, the strength of columns and their foundations shall be checked to ensure that excessive loads are not applied.

Heat exchangers shall not be included in a cleaning circuit to prevent possible plugging of the tubes by fouling deposits. All pipes, valves and instruments which are not included in the cleaning circuit shall be blanked off or removed.

In preparation for the cleaning of distillation columns the feed to the columns should be reduced for 4 hours before shutdown, whilst the column temperatures are lowered. Lighter fractions should then reach the bottom sections and effect a washing-down of the heavier components from the column trays and wall.

5.2.1 Acid cleaning of columns

For the acid cleaning of carbon steel columns, water should be “rained” from top to bottom, filling all trays and the bottom of the column with water to create a sufficient level for pump suction. After the piping and pump have been checked for leaks by water circulation, inhibited concentrated hydrochloric acid or sulphuric acid should be introduced into the columns until the required concentration is reached; this is usually 2% to 5% by weight for hydrochloric acid and 4% to 10% by weight for sulphuric acid. In-situ cleaning can be performed by circulation of cleaning agents using a mobile unit.

When 12-Cr internals are present the acid shall be circulated at ambient temperature. Any hydrogen sulphide produced shall be vented to the flare and the acid concentration shall be checked regularly during circulation, maintaining the strength by adding fresh acid. After draining the acid and water flushing, neutralisation shall be carried out by introducing a mixture of water and caustic soda into the column, until a 1% to 2% by weight alkaline solution is obtained.

5.2.2 HP water jet cleaning

Columns, vessels and reactors may also be cleaned by HP water jetting using the tank cleaning head as described in (4.4.2.2). When this device is used, trays need not be removed and personnel do not need to enter the units during cleaning.

5.3 CLEANING OF SHELL-AND-TUBE HEAT EXCHANGERS

5.3.1 General

If the fouling of heat exchangers is not too severe and mechanical cleaning is deemed

unnecessary, then in-situ cleaning can be performed by circulating cleaning agents through the equipment via a mobile unit; if necessary several heat exchangers can be lined up in series.

To avoid air pockets in the heat exchanger, the flow in the circuit shall be upwards.

The cleaning procedure for heat exchangers is basically the same as for columns, vessels and reactors, but the cleaning agent should be prepared at the proper concentration beforehand.

Severely fouled heat exchangers should be cleaned in the cleaning yard by immersion. Heavy organic deposits on the tube side may require additional HP water jet cleaning. Some examples of cleaning methods are given in Appendix 3.

Hydrogen sulphide is formed, sometimes in large quantities, when hydrochloric acid is used to remove iron sulphide deposits. This may cause stress corrosion cracking of steels with a Brinell hardness above 235. This type of cracking has been experienced in bolts (AISI 4140 or 5 Cr-0.5 Mo) and in flanges of expansion bellows (5 Cr-0.5 Mo) when cleaning heat exchangers in platforming units. Such heat exchangers should therefore be dismantled and cleaned by immersion after removal of the bolts and expansion bellows. Produced hydrogen sulphide shall be vented safely. Materials with hardness in accordance with NACE MR0175 are resistant and may be left in place.

5.3.2 Heat exchangers in hydrofluoric acid (HF) service

Tube bundles in HF service shall be made safe for withdrawal by soaking in, or circulating with, a solution of 2.5% by weight sodium carbonate for one hour at a temperature of 50 °C, while maintaining the pH above 10. After draining the solution the bundles may be withdrawn and then cleaned with high pressure water.

Equipment in HF service shall always be treated as if it may contain residual HF after neutralisation; hence full HF precautions shall be taken, including the use of all protective gear, at the time of opening.

5.3.3 Heat exchangers in furfural extraction units (extract mix vaporiser)

The tube bundles should be blasted using high pressure water to remove loose scale, hydrocarbons and loose coke from inside the tubes.

In order to remove coke deposits completely, the bundles should then be heated to 425 °C in a furnace, soaked at this temperature for 4 hours and allowed to cool. The maximum heating/cooling rate should be 150 °C/h. During the cooling cycle the bundles should be air-cooled at the above rate to 260 °C by opening the furnace doors and left to cool. The coke deposits will then be completely dry and flaky and easily removed with a second 700 bar water condensate blast.

Furnace heating often results in tube leakage at the tube-to-tubesheet joint, and tube ends may need to be expanded if leakage occurs during the hydrostatic test.

Alternatively ultra-high pressure water jetting can be applied (see 4.4.11) or blasting with a slurry.

5.3.4 Heat exchangers in TGU/visbreaker units

A successful method of cleaning exchangers with tar-like deposits is as follows:

- Circulate heavy aromatics (xylene, or toluene) or cat-cracker (cc) cycle oil through the exchangers prior to opening.

  NOTE: Since xylene, toluene and cc cycle oil are potentially carcinogenic materials, suitable precautions shall be taken.

- Steam out the exchangers using LP steam, or flush with gasoil, to remove the traces of xylene, toluene or cc cycle oils. Steaming has the additional advantage of drying out the deposits, making them brittle.

- Remove the bundle and clean with an HP water jet.

5.4 CLEANING OF BOILERS

5.4.1 Steam/water side cleaning

When the performance of boilers becomes inefficient, chemical cleaning may be required to remove deposits inside the boiler tubes.

A detailed procedure for the chemical cleaning of boilers is given in Appendix 1.

5.4.2 Flue gas side cleaning

The flue gas side of boiler tubes can be effectively cleaned and neutralised by injecting ammonia gas and flashing hot boiler feed water in the flue gas path of the boiler. The method is based on the principle that by circulating cold treated water through the boiler tubes, steam with ammonia vapour will condense on the cold surface of the boiler tubes, thereby washing off and neutralising acidic deposits.

For a detailed procedure for cleaning the flue gas side of boilers, reference is made to Appendix 2.

5.5 CLEANING OF PROCESS FURNACE TUBES

5.5.1 Common methods

Steam-air decoking, shot jet cleaning and HP water jet cleaning are the most commonly used methods for the internal cleaning of furnace tubes. Shot jet cleaning shall not be used in vertical tubes.

For steam-air decoking, steam and air are supplied to the tube coil, and coke is removed by the controlled combustion of the deposits. The combustion reaction shall be carried out in a narrow temperature range whose upper limit is dictated by the metallurgical strength of the furnace tube metal. The lower limit will be determined by the heat required to sustain the reaction.

The maximum allowable skin temperatures to prevent oxidation of the tube material during burning are:

Carbon steel and 0.5 Mo steel:		565 °C
2.25 Cr, 1 Mo steel:		620 °C
5 Cr, 0.5 Mo steel:		650 °C
9 Cr, 1 Mo steel:		705 °C
High-alloy Cr-Ni steels:	AISI 304/316/321/347:	870 °C
	AISI 309:	1090 °C
	AISI 310:	1150 °C

The maximum allowable tube wall temperature can be controlled with steam-air mixtures containing not more than 10% by weight air. Decoking of carbon steel tubes shall be carried out very carefully since the “burning” temperature of 500 °C to 550 °C is very close to the maximum allowable temperature.

For details of shot jet cleaning of furnace tubes, reference is made to (4.3).

HP water jet cleaning is described in (4.4). Appendix 4 gives some practical guidelines on tube cleaning.

5.5.2 Hydraulic pigging

Hydraulic pigging is very effective in removing coke from the internal surfaces of tubing, bends, etc.

Specially developed pigs, with studs screwed into them on the outer circumference, are passed through the heater tubes and the convection bank, using water as a propellant. The studs, in various shapes and sizes, remove coke from the tube wall as the pig travels through the tubes. The scale and coke are carried by the water out of the heater tubes and collected in a tank basin where the coke and water are separated by a strainer basket.

Before starting the pigging exercise with the studded pig, a foam pig is routed through the coil to determine the coke build up by fingerprinting the pressure profile in the tubes, and to check for any restrictions that may remain. Equipment such as thermowells have to be removed from the coils. The first decoke pig is undersized with the correct studs and assisted by a foam pig. As it moves through the coil, pressure increases when obstacles such as coke layers and bends are encountered. From the pressure profile one can determine the location of the coke in a certain section of the tube, as the pressure increase in each bend is clearly distinguished from any coked section.

Tungsten wedge studs are used to break excessively hard coke layers. However, to avoid tube erosion, less aggressive studs are normally selected.

Examples of this technique can be found in sections 4.5 and 6 of the SIOP Maintenance and Inspection Bulletin, 16th edition (December 1996).

5.6 CLEANING OF PIPING SYSTEMS

5.6.1 Removal of rust

For cleaning of oxygen systems see DEP 31.10.11.31-Gen.

The system should first be degreased by circulating water at 80 °C and adding a suitable degreasing agent. The solution should be circulated at this temperature for 2 hours. The system should then be drained and washed out with water to the process water effluent treating system.

The rust can then be removed by circulating inhibited 2% to 5% by weight hydrochloric acid until a sample shows that the reaction is complete.

Finally, steam condensate should be circulated at 40 °C and a passivating phosphate mixture added until a 2% solution is obtained. The solution should be circulated for 2 hours. The system should then be drained to the process water effluent treatment system, and then dried with air.

5.6.2 Cleaning without circulation

For cleaning piping systems without circulation facilities, a trailer with tanks, pump and heating facilities should be connected to each end of the system. The cleaning agents should then be pumped from one trailer to the other, as often as required.

NOTE: All instrumentation components, all relief valves and all components susceptible to metallurgical attack shall be removed or blanked off.

5.6.3 Steam blowing

The purpose of steam blowing is to remove debris, loose scale and rust from recently welded or renewed steam lines suitable for steam turbine operation. The effectiveness depends on the steam velocity, the change of temperature in time and the number of blows.

Line cleaning should not commence until all related piping and process equipment are fully installed, the system has been checked for conformance with the piping and instrumentation diagrams, and the piping systems have been hydrotested. Temporary piping and silencers for depressurising to atmosphere should be properly anchored.

All restrictions in the piping such as orifice plates, flow measurement tubes and thermowells shall be removed prior to steam blowing. Control valves shall be replaced with spool pieces.

Steam should be blown from a clean system to uncleaned systems. In order to thermally shock the piping to remove mill scale, the steam valve controlling the blow down should be of the quarter turn type (quick opening).

The valve should be located well upstream of the piping to be cleaned. At the inlet flange of the silencer, a target strip of polished copper or aluminium shall be clamped to judge the finished cleanliness. Blows should first be made at low pressures to remove large objects in the piping, gradually raising the pressure during later blows to the maximum operating pressure. Between the blows there should be a cool down period of at least 60 minutes for uninsulated pipes and 240 minutes for insulated pipes. A system is considered to be

acceptably clean when the target plate has less than a predetermined number of impact pock marks. The following requirements apply for blowing steam lines:

- steam flow during blowing shall be at least three times the maximum flow rate during operation;
- there shall be not more than one total particle count (pock mark) per square centimetre of target plate surface;
- there shall be no evidence of embedded material (e.g. weld splatter, sand, etc.). Target plates shall not show individual rough impressions;
- the blowdown shall be of not less than 10 minutes duration;
- at least 15 blows shall be made;
- if the piping is not to be put immediately into service, the system should be purged with nitrogen to remove any air and should be placed under an inert nitrogen blanket.

5.6.4 Air blowing

If it is not possible to achieve the necessary steam velocities required for steam blowing or if it is not convenient to use steam because of the possibility of residual liquids in the line that may damage machines or instrumentation, air blowing should be substituted. Examples of this are fuel lines and instrument air lines.

Preparations are identical to those for steam blowing. Air is usually supplied from temporary high-pressure large-capacity air compressors because the permanent instrument air compressors do not normally have sufficient capacity. These rental air compressors are supplied with aftercoolers and coalescers to remove oil from the compressed air system. An air reservoir shall be available during the blowdown process. The piping is then cleaned by pressurising the piping system and then opening a temporary quick acting valve to allow depressurisation (via a silencer) to atmosphere.

Some thermal shocking can be achieved by running the compressor without the aftercoolers in operation. However this is insufficient to obtain any significant thermal cycling. It is recommended that piping be internally shot blasted prior to air blowing.

In general, between 60 and 80 blows for each system will be necessary to ensure cleanliness. An indication of the air flow necessary for the cleaning process can be determined by calculating the Disturbance Factor (DF):

$$DF = \frac{R_b^2 \, d_o}{R_o^2 \, d_c}$$

where R_b = flow rate during blowing,

R_o = flow rate during operation,

d_c = density of cleaning medium,

d_o = density of operating medium

Experience has shown that with DF greater than 1.5 the line is well cleaned and the polished metal target shows little or no evidence of pitting after the air blow.

6. DESLUDGING OF CRUDE OIL TANKS

6.1 GENERAL

Sludge accumulation in crude oil tanks is a common occurrence and can give rise to serious problems, such as:

- a significant decrease in effective storage capacity;
- the inability to set the floating roof evenly on its legs;
- difficulty with draining water from the tank;
- sludge deposits may accelerate tank floor corrosion;
- additional gas-freeing problems, if entry is required;
- manual clean-out of accumulated sludge is expensive and time-consuming, and involves a loss of hydrocarbons.

The best way of dealing with tank sludge is to prevent it from accumulating to an excessive level and so avoid having to take a tank out of operation for a major sludge removal operation. Given below are methods to minimise or prevent sludge accumulation during operation and methods to remove sludge when the level has become too high.

For sludge disposal, see section 7.

6.2 METHODS

Method 1 - Use of side-entry mixers
Method 2 - Use of clean-out jets

Methods 1 and 2 are preventive and can be applied during normal operation.

Method 3 - Use of hot diluents/external circulation with heat
Method 4 - Use of live steam injection

Methods 3 and 4 are corrective and should be applied when sludge accumulation has reached such a high level in the tank that the roof can no longer be settled on its legs. Special facilities are required and the tanks will have to be taken out of normal service to allow the sludge to be removed. The use of side-entry mixers or clean-out jets, if fitted, will speed up removal.

NOTE: 1. The use of desludging additives will have only a marginal effect at ambient temperatures.

Static electricity may be generated when applying any of the above methods. Refer to the Shell Safety and Health Committee publication “Static electricity, technical and safety aspects”.

The requirements of national and/or local regulations for the gas freeing of and entry into storage tanks shall be complied with. Reference shall also be made to the Shell Safety and Health Committee publication “Gas-freeing and cleaning of oil storage tanks”.

Method 1 - Use of side-entry mixers:

Side-entry mixers are installed to keep solids in suspension and so prevent them from settling as sludge on the bottom of the storage tank. The mixers must be correctly installed, well maintained and operated according to a specific procedure to suit the type of crude oil, the tank size and the climate.

The requirements for the design, fabrication, assembly, testing and installation of side-entry mixers are given in DEP 31.51.10.31-Gen.

There is a relationship between the presence of sludge, the angle of the mixer to the tank radius, the crude oil type and the storage temperature. Sludge build-up will occur if tank mixers are turned off for periods of time.

Additional requirements for the installation of mixers are as follows:

- Swivel-angle mixers are preferred to the fixed-angle type. Complete liquid turnover in the tank is not required, but a flow pattern in the lower part of the tank should be maintained to keep solids in suspension.
- Power input should not be less than 1.4 W/m^3.
- It should be noted that in many existing installations fixed-angle mixers at 20° offset to the tank radius are installed. In large diameter tanks in particular, “dead spots” may be formed with this type. If these dead spots present a problem, changing to the swivel-angle type should be considered.

Method 2 - Use of clean-out jets (jet mixing):

Tank circulation and sludge entrainment may also be achieved by means of a jet nozzle, inclined to give a stream some 5° below the horizontal in order to sweep the floor of the tank. This can best be done in a partly filled tank, because the roof should be floating to avoid a gas cap being formed.

Unless a circulation system is already part of the tank installation, external piping together with a high-capacity, high-pressure pump will be required.

Methods 1 and 2 have the following advantages over the corrective methods 3 and 4.

- a substantial saving in clean-out costs;
- better environmental protection (less sludge to be disposed of);
- reduced product losses.

Method 3 - Use of hot diluents/external circulation with heat

This method may also utilise the following alternatives:

- hot diluent and side-entry mixers;
- external circulation and jet mixing;
- external circulation and side-entry mixers.

A circulation pump and pipework system is necessary for external circulation of the tank contents through a heat exchanger.

Waxy deposits together with other sediments will pose considerable problems during tank cleaning, especially if they contain waxes with high melting points. The use of a hot diluent will make it possible to recover most of the waxes for re-use. Gas oil or a non-waxy crude at a temperature in accordance with the melting point of the wax can be added, but care shall be taken in selecting the hot diluent to avoid boiling problems.

In general it has been found that when the mixing ratio of the wax and the diluent is about 1:5, the mixture will be pumpable under ambient conditions.

Method 4 - Use of live steam injection

With the tank at minimum level, live LP steam should be introduced via a drain line and the tank contents heated to the temperature required to dissolve sludge into the crude oil over a period of several days. The steam rate should be restricted to avoid or reduce the physical vibration of the tank and associated pipework caused by the shock from the implosion of steam pockets.

7. DISPOSAL OF EFFLUENTS AND SLUDGE

The following recommendations are given, aimed at minimising or eliminating adverse impact on the environment.

- Waste gases released during cleaning should be treated, e.g. via a caustic treater, to remove acidity or toxic content, before disposal through a safe outlet.
- Liquid effluents should be neutralised in a holding tank or basin, and any hazardous compounds suitably treated to meet environmental requirements. The biochemical and chemical oxygen demand of the effluent shall meet the Principal's effluent standards.
- Non-hazardous solid sludge should, wherever possible, be incinerated. Sludges should be incinerated after pre-treatment, e.g. dewatering and/or deoiling. Properly engineered land farming can sometimes be applied if there are no hazardous non-biodegradable compounds or heavy metals. Hazardous sludge should be drummed and handled by specialised waste handling contractors.
- Spent catalyst should be returned, if possible, to the supplier. If this is not feasible, spent catalyst should be sent to an approved spent catalyst processor working according to the principle of total recycle, i.e. metal reclamation with no hazardous residue left. Spent FCC catalyst may be disposed of for re-use in encapsulated form (e.g. cement manufacture, asphalt filler).

Cleaning operations shall be conducted in such a way that they will not lead to unacceptable pollution of the environment, as follows:

- Surrounding soil/pavement (use of permanent/temporary soil protection).
- Surface water (use of proper effluent water treating facilities).
- Air (use of condensers/filters/incinerators).
- Waste (use of environmentally acceptable disposal route)

Cleaning operations may result in excessive temporary environmental pollution. This shall be prevented by careful planning, e.g. draining to a temporary tank from which the effluent is either reprocessed or drained off to the appropriate effluent water treating facilities.

Waste from cleaning operations usually comes into the category of chemical/hazardous waste, for which disposal costs are high. Segregation from other wastes may be economically beneficial.

8. REFERENCES

In this DEP reference is made to the following publications:

NOTE: Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments/supplements/revisions thereto.

SHELL STANDARDS

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
Gaseous oxygen systems	DEP 31.10.11.31-Gen.
Side-entry mixers for storage tanks	DEP 31.51.10.31-Gen.

Shell Safety and Health Committee Publications:
"Asphyxiation - the hidden danger"
"Gas-freeing and cleaning of oil storage tanks"
"Hydrogen sulphide"
"Static electricity, technical and safety aspects"

AMERICAN STANDARDS

Sulphide Stress Cracking Resistant Metallic Materials for oil field equipment	NACE MR0175
Protection of Austenitic Stainless Steels and Other Austenitic Alloys from Polythionic Acid Stress Corrosion Cracking During Shutdown of Refinery Equipment	NACE RP0170

Issued by:
National Association of Corrosion Engineers
1440 South Creek,
Houston, Texas 77084,
USA

9. BIBLIOGRAPHY

NOTE: The following documents are for information only and do not form an integral part of this DEP.

SHELL DOCUMENTS

Papers and Minutes of 1990 Thermal Cracking Meeting — Report MF 90-0450

Experiences with the SpongeJet surface preparation technique — Report OP 97.20188

Shell Safety and Health Committee Publications:
"Contractor safety"
"Environmental management guidelines"
"Personnel protection equipment guide"
"Waste management guidelines"

SIOP Maintenance and Inspection Bulletin, 16th edition (December 1996)

EXTERNAL DOCUMENTS

Institute of Petroleum (IP) "Refining safety code"

Issued by:
The Institute of Petroleum,
61, New Cavendish Street,
London W1M 8AR
U.K.

APPENDIX 1 PROCEDURE FOR THE CLEANING OF BOILERS ON THE STEAM/WATER SIDE

Although this procedure covers all the requirements of chemical cleaning, its application depends on the type of boiler, the severity of fouling and the results of a laboratory investigation. The description is based on a practical example for an existing boiler and is intended as a guide. The procedure given by the cleaning contractor can be evaluated using this guide.

1. PREPARATION

- Apply heavy blowdown from mud drum to remove solids as much as possible.
- Disconnect the drum internals and leave them in the drum in such a way that the flow will not be disturbed (sometimes this may entail removal from the drum).
- Take care that chemicals will not enter the water feed or steam lines (by e.g. overflow lines, backflush with condensate through superheater header). Positive isolation shall be assured and spading should be used for this purpose.
- Remove the gauge glasses and replace them after the cleaning work is completed. Provide a temporary gauge glass for the cleaning process.
- Isolate (or break) all instrument lines.
- Provision shall be made on the top of the steam drum for the release of gases and an overflow back to the dosage tank, both lines to be provided with a valve.
- The downcomers should be temporarily covered by caps inside the drum.
- Arrange temporary piping for circulation, filling and effluent.
- Disconnect blowdown lines, where necessary, to allow complete draining of the boiler to the point of disposal.

2. ALKALINE BOIL-OUT

- Fill the boiler completely with demineralised water or boiler feed water (BFW) to the low level in the drum and check the system for leaks.
- Prepare the chemical solution in dosing tanks.
- Check that all valves on the boiler are in the correct position, start the water circulating and dose the chemical solution into the boiler. Stop the circulation and isolate the pump.
- Raise the temperature of the boiler at a maximum rate of 35 °C/h up to 140 °C using one burner and, if required, a second burner periodically.
- At this temperature it should be possible to maintain a natural circulation in the boiler, by blowing off saturated steam intermittently via the drum vent. The water level shall be observed; a 1% to 2% intermittent blowdown during circulation should give the required results.
- After completion of the operation, the boiler should be allowed to cool gradually to about 80 °C and the system drained to a holding tank.
- Refill the system with water and start the circulation; continue for about half an hour. The boiler should then be drained again and inspected. Repeat if necessary until the water is clear.

3. ACID CLEANING

- Use a circulation pump able to maintain a liquid velocity of max. 0.5 m/s.
- Fill the boiler with demineralised water or BFW to the low level in the drum and check the system for leaks.
- Start the circulation pump.

- If considered necessary, the water may be heated by firing the boiler, or by filling with hot water and firing.
- When the required temperature is reached, sufficient water should be drained to the oil-free drain system to allow the dosage of acid; reference is made to (3.3) for the concentration and temperature to be used. To prevent temperature drop, care shall be taken to avoid any draught in the boiler.
- Premix the inhibitor and acid and introduce it gradually into the water circulation. The chemicals used are:

  Hydrochloric acid, 2% to 5% by weight;
  Ammonium bifluoride 1%

  The level of acid solution in the steam drum shall be kept at a minimum level, typically just visible in the drum gauge glass.
- Maintain the circulation and check the ferrous and ferric ion and acid concentration every 30 minutes. If direct visual inspection is difficult, the duration is best determined by experience and chemical analysis.
- The acid solution shall be drained into a tank and neutralised to a pH 7 (± pH 1), using where possible the previously drained alkaline effluent. The tank content may then be drained slowly into the sewer (see 3.7).
- The boiler should be refilled with water at a temperature to give a maximum difference of 50 °C with the wall temperature of the drum.
- Circulate the water for about one hour and drain the boiler directly into the oil-free drain system.
- Repeat the water flushing cycle if required.

4. COPPER REMOVAL (if required)

- Refill the boiler with water and bring the temperature up to 55 °C.
- Start circulation.
- Dose the inhibitor into the system then add citric acid to obtain a concentration of 0.5%.
- When the iron readings have stabilised, raise the pH to 9.5 by adding ammonia.
- Dose sodium bromate to a concentration of 0.5% and maintain circulation until the copper readings have levelled out.
- Drain the copper removal solution into a tank and add sufficient sodium hydroxide to the solution to obtain a pH of at least 11. A quantity of approved oxygen scavenger should be added to reduce the bromate and help settle the copper; safety precautions shall be observed when handling the scavenger.
- The settling out of the copper will take about 24 hours. The liquid should be drained into the sewer, while the sludge remains in the tank for safe and environmentally acceptable disposal elsewhere (see 3.7).
- Flush out by water circulation, and drain.

5. PASSIVATION

- Refill the boiler with water and bring the temperature up to 55 °C.

Method 1

- Inhibitor and citric acid should again be added to remove iron oxide, and the pH raised to 9.5 by adding ammonia.
- Sodium nitrite should then be dosed into the system to a concentration of 0.25% and circulated for about 4 hours.
- The boiler can then be drained to the process water effluent rundown system for

biotreatment, ventilated and inspected.

- Before the boiler can be taken into service again, it shall be refilled with water at a slight overpressure and drained, for removal of the passivation chemicals.

Method 2

- Drain hydrochloric acid and sulphuric acid solution under a nitrogen blanket.
- Flush boiler with de-aerated BFW.
- Passivate with alkaline passivating solutions (e.g. ammonia, sodium carbonate etc.)

APPENDIX 2 DETAILED PROCEDURE FOR CLEANING AND NEUTRALISING THE FLUE GAS SIDE OF A BOILER USING AMMONIA

1. SHUTDOWN PREPARATIONS

- Pipework for cold treated water circulation inside the boiler should be prepared in accordance with Figure 2-1 of this Appendix.
- An ammonia distribution system, made of 6 mm steel tubing and provided with a pressure regulator, is required for the supply of ammonia from cylinders into the flue gas path. The ammonia is injected directly into hot boiler feed water and distributed via the soot blowers and lances.
- To prevent pollution problems, temporary arrangements shall be made for collection and disposal of water and sludge.

  NOTE: Adequate facilities are necessary to drain the liquid effluent from the combustion chamber.

2. SHUTDOWN ACTIVITIES

- After the boiler has been shut down and cooled, the following items shall be blanked off or disconnected:

  (a) The ducting to main stack.
  (b) The steam outlet to main header.
  (c) The fuel oil and fuel gas lines.

- The forced-draught fan should be run until the boiler is cool, but remain out of operation during flue gas side cleaning.
- Pre flue gas side cleaning activities:

  (a) Open the steam drum and install covers on the downcomers to avoid a "short circuit". The cold treated water shall flow via screens.
  (b) Install additional lances, with adequate supports, inside the boiler.
  (c) Close all manholes.
  (d) Check the possibilities of sludge drainage via e.g. furnace manhole or bottom drains. Additional drains may be required.
  (e) If applicable, protect the bottom refractory with plastic sheeting.
  (f) A sufficient number of ammonia cylinders shall be available e.g. approx. 1200 kg of ammonia will be required for a 130 t/h HP or MP boiler.

3. FLUE GAS SIDE NEUTRALISATION AND CLEANING

(a) Circulate cold treated water through the boiler tubes. Ensure that it will flow through the superheater by throttling the valve to the economizer while opening the valve to the superheater. Initially the water shall drain into the oil-free drain system until analysis of samples shows that it can be returned to the BFW tank.

(b) Slightly open the valve leading to the burner lances.

(c) Fully open the isolating valve between the eductor assembly and, if applicable, the soot blower piping.

(d) Open the ammonia supply valves to the header and throttle the discharge pressure to about 2 bar (ga).

(e) Throttle the supply valve for hot BFW from the de-aerator.

(f) If using an eductor, reduce the ammonia flow to a minimum, maintaining the sample at the nearest connection at pH 13. If using direct ammonia injection, check that the pH of the sludge is between 11 and 13.

(g) Start the neutralisation cycle, e.g. by opening a pair of soot blowers or lances, starting from the top of the boiler and working downwards. For operational reasons the soot blowers can be operated on automatic sequence control one series after the other, while keeping a number of lances in operation.

If using an eductor, care shall be taken to prevent back-pressure in the ammonia supply line, which can occur when transferring from one lance or soot blower series to another. A throttled flow to some lances shall be maintained.

(h) The neutralisation should be continued until the effluent from the casing drain has a constant pH of between 11 and 13. A regular check of sludge disposal shall be made.

(i) Stop the ammonia injection, but continue with the BFW washing for about 3 hours or until the effluent from the drain becomes fairly clear.

(j) Stop the cold water flow and blank off the eductor assembly, if applicable.

(k) Open the manholes for an initial visual inspection. Any section found to be insufficiently neutralised or cleaned will have to be re-treated or be manually cleaned.

(l) Shovel out any soot accumulated on the boiler floor or wash out by water spray. Manual cleaning may be required where loose scale is clinging to tube surfaces.

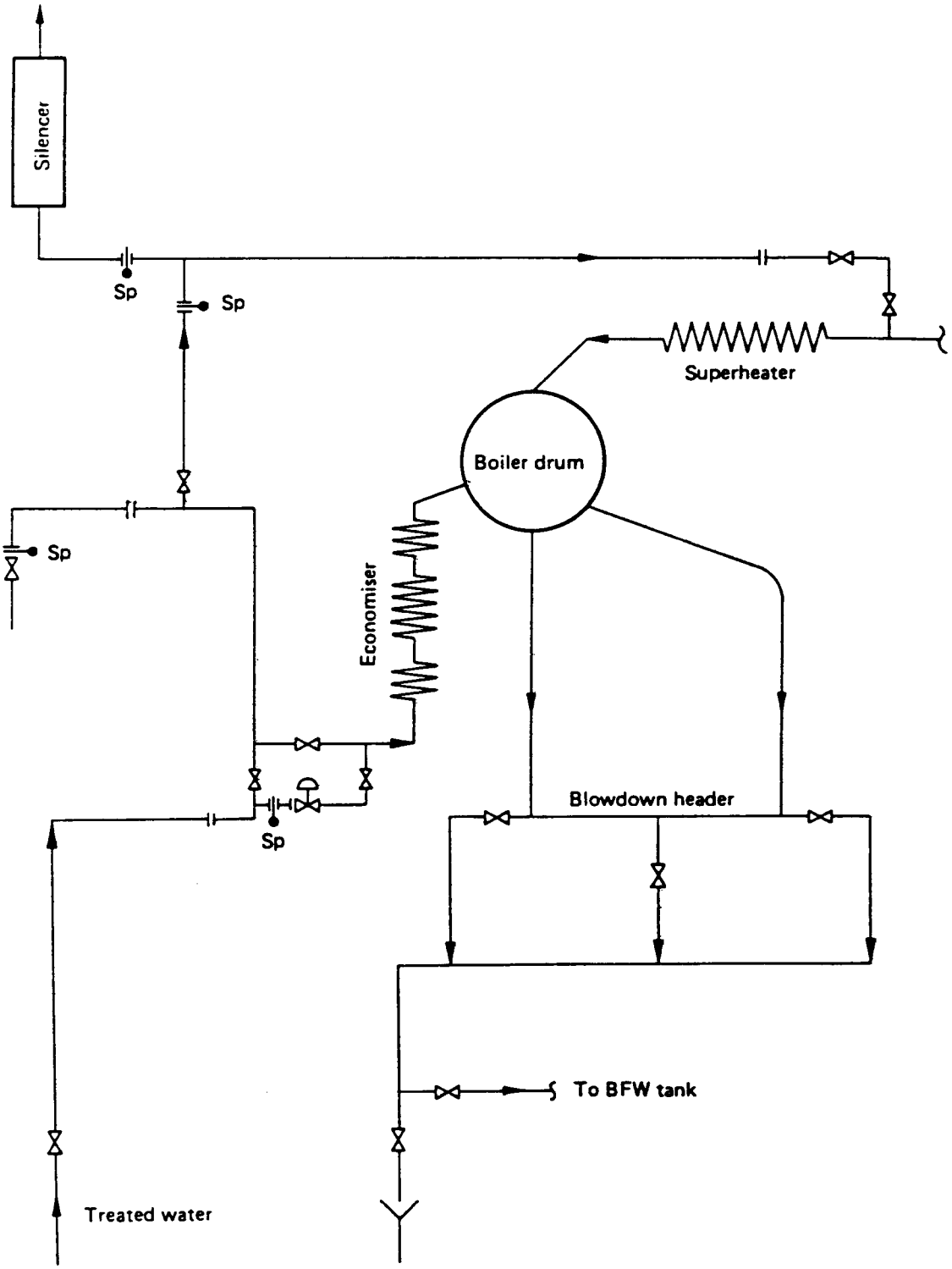
(m) Dry the external tube surfaces of the boiler and the insulation using hot BFW flow inside the tubes (approximately 140 °C). Return the hot BFW back to the tank via a temporary line. Ensure, however, that all the valves on the return line are kept open during this operation with high-pressure boiler feed water. Lock the valves in the open position. Continue the drying operation until the boiler tube surfaces and the insulation are thoroughly dried, which may take up to 3 days. The forced-draught fan shall not be used. Some natural draught is sufficient to expel water vapour (cracked open manholes in the bottom of the boiler or in the flue gas ducting).

Neutralising/cleaning using sodium bicarbonate

In some cases, fuel oil may contain high levels of sulphur, which can lead to a very high level of acidity in the flue gas deposits and in the refractory.

Boilers can suffer external corrosion of tubes, particularly those buried in refractory. To prevent corrosion during shutdowns a thorough neutralisation procedure shall be applied, particularly for boilers firing fuel oils containing appreciable amounts of sulphur. To prevent corrosion of tubes buried in refractory the acidic compounds in the refractory, originating from the flue gas, should be neutralised using a saturated solution of sodium bicarbonate. The solution shall be percolated over and through the refractory and the discharge pH measured. The process can be considered complete once the pH is between 11 and 13.

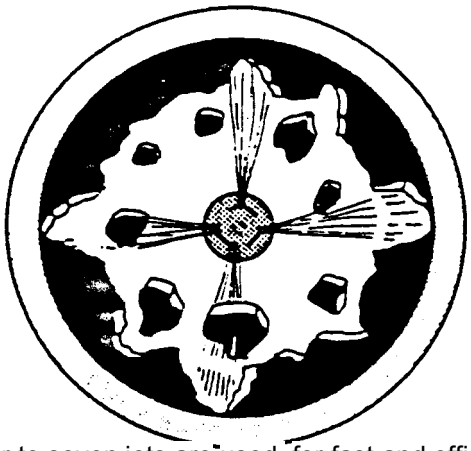
Figure 2-1 Cold water circulation through the tubes for ammonia cleaning on the flue gas side of a single drum boiler



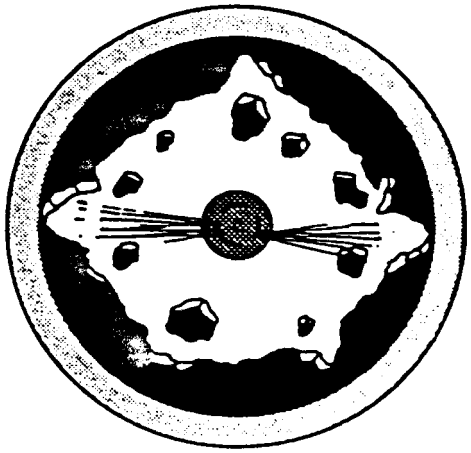
APPENDIX 3 EXAMPLES OF CLEANING OF SHELL-AND-TUBE HEAT EXCHANGERS

Type of deposit	Material of construction	Method
Scale/sludge	Al-brass Monel Cupro-nickel	Degreasing : steam clean Circulate 2 hours at 80 °C Acid cleaning : 2% inhibited hydrochloric acid Circulate 6 hours Neutralising : 2% metal passivator Circulate 2 hours at 80 °C
Algae	Carbon steel	Degreasing : steam clean Circulate 2 hours at 80 °C Acid cleaning : 2% inhibited hydrochloric acid Circulate 6 hours Neutralising : 2% metal passivator Circulate 2 hours at 80 °C
Light oil		Cleaning : steam clean Circulate 8 hours at 80 °C
Heavy oil		10% carbon stripper NF in Shell Sol E Circulate 8 hours at 45 °C 7.5% liquid clean Circulate 8 hours at 85 °C
Light oil (inside tubes) Heavy oil (shell side)		*Shell side* 10% carbon stripper NF in Shell Sol Circulate 8 hour at 45 °C *Inside tubes and shell side in series* 7.5% liquid clean Circulate 8 hours at 85 °C
Scale	Carbon steel	Degreasing : steam clean Circulate 2 hours at 80 °C Acid cleaning : 2% inhibited hydrochloric acid Circulate 6 hours Neutralising : 2% metal passivator Circulate 2 hours at 80 °C

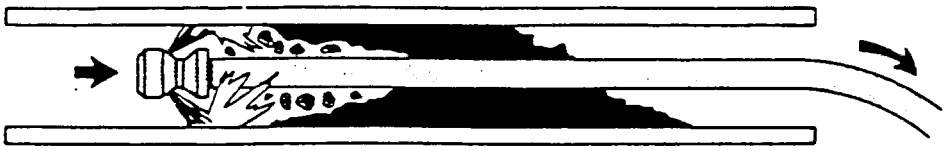
APPENDIX 4 FURNACE TUBE CLEANING



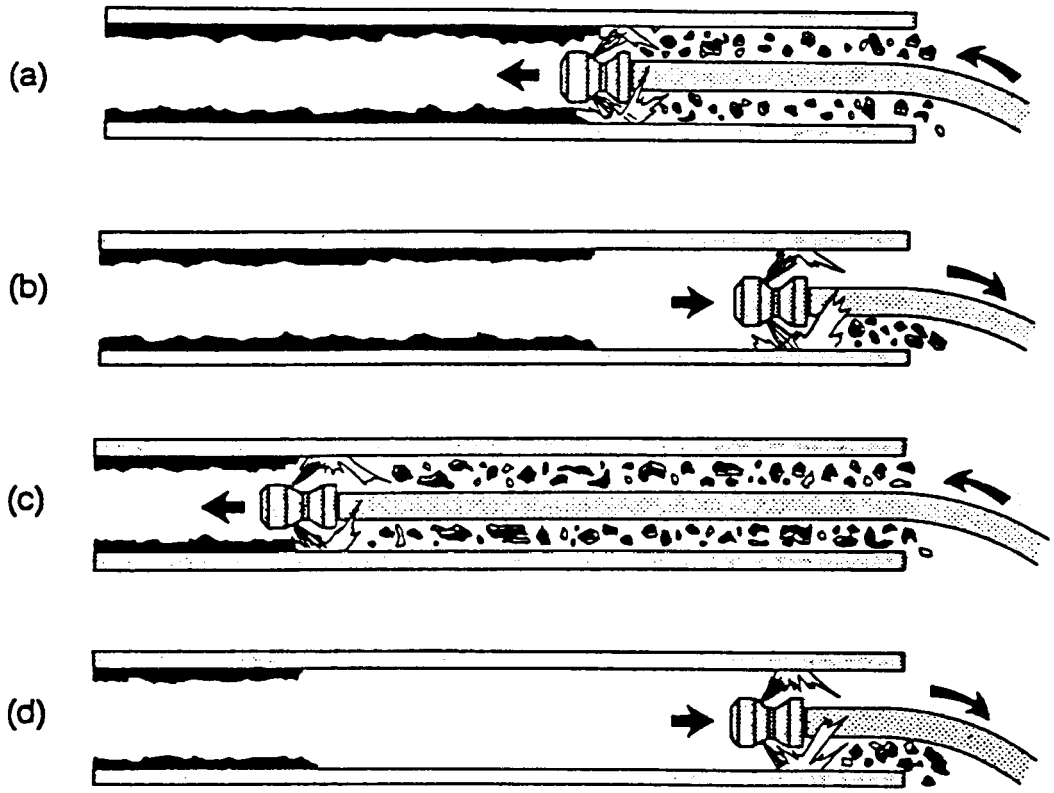
Normally, nozzles with four to seven jets are used, for fast and efficient cleaning



If the coke is very sticky, it is better to use a nozzle with two jets. The best effect is with an 85 degree jet nozzle.



Sometimes the broken coke is very difficult to remove. The correct sequence when faced with this situation is to take small cuts, withdrawing the lance frequently, thus preventing accumulation of broken coke behind the nozzle, as illustrated below.



Note: The lance shall have a rigid section of length not less than one pipe diameter.

APPENDIX 5 HIGH-PRESSURE WATER JET DATA

Table 5-1 Maximum Working Pressure for Cylindrical Jets

Reaction force 250 N			Reaction force 150N	
Nozzle	Pressure, bar (ga)		Nozzle	Pressure, bar (ga)
0.8	2662		0.8	1596
1.0	1704		1.0	1020
1.2	1183		1.2	709
1.5	757		1.5	453
1.8	525		1.8	314
2.0	426		2.0	255
2.2	352		2.2	211
2.4	295		2.4	177
2.6	249		2.6	150
2.8	217		2.8	130
3.0	189		3.0	113
3.2	166		3.2	100

Table 5-2 Maximum Working Pressure for Flat Blade Jets

Reaction force 250 N			Reaction force 150N	
Nozzle	Pressure, bar (ga)		Nozzle	Pressure, bar (ga)
0.8	3775		0.8	2344
1.0	2416		1.0	1500
1.2	1677		1.2	1042
1.5	1073		1.5	667
1.8	745		1.8	463
2.0	604		2.0	375
2.2	499		2.2	310
2.4	419		2.4	260
2.6	357		2.6	214
2.8	308		2.8	191
3.0	268		3.0	167
3.2	235		3.2	147

Table 5-3 Flow rates for "Flat blade Nozzle"

Pressure	Nozzle diameter (mm)											
bar (ga)	0.8	1.0	1.2	1.5	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
1000	8.9	14.0	20.1	31.4	45.3	55.9	67.7	80.5	94.5	109.6	125.9	143.2
800	8.0	12.4	18.0	28.1	40.5	50.0	60.5	72.0	84.5	98.0	112.6	128.0
600	6.9	10.8	15.6	24.4	35.0	43.3	52.4	62.4	73.2	84.9	97.5	110.9
500	6.3	9.9	14.2	22.7	32.0	39.6	47.8	57.0	66.8	77.5	89.0	101.3
400	5.7	8.8	12.7	19.9	28.7	35.0	42.8	50.9	59.8	69.3	79.6	90.6
300	4.9	7.7	11.0	17.2	24.8	30.6	37.0	44.1	51.8	60.0	68.9	78.4
200	4.0	6.2	9.0	14.0	20.3	25.0	30.3	36.0	42.3	49.0	56.3	64.0
150	3.5	5.4	7.8	12.2	13.7	21.7	26.2	31.2	36.6	37.2	48.7	55.5
100	2.8	4.4	6.4	9.9	14.3	17.7	21.4	25.5	29.9	34.7	39.8	45.3
	Flow l/min											

Table 5-4 Flow rates for "Cylindrical Nozzle"

Pressure	Nozzle diameter (mm)											
bar (ga)	0.8	1.0	1.2	1.5	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
1000	12.8	21.0	28.9	51.3	64.9	80.2	97.0	115.5	135.5	157.2	180.4	205.3
800	11.5	17.9	25.8	45.9	58.1	71.7	86.8	103.3	121.2	140.6	161.4	183.6
600	9.9	15.5	22.4	39.8	50.3	62.1	75.2	89.5	105.0	121.8	139.8	159.0
500	9.1	14.2	20.4	36.3	45.9	56.7	68.6	81.7	95.8	114.1	127.6	145.2
400	8.1	12.7	18.3	32.5	41.0	50.7	61.4	75.1	85.7	99.4	114.1	129.8
300	7.0	10.9	15.8	28.1	35.6	43.9	53.1	63.3	74.2	86.1	98.8	112.4
200	5.7	8.9	12.9	22.9	29.1	35.9	43.3	51.6	60.6	70.3	80.7	91.8
150	4.9	7.8	11.2	17.5	25.1	31.0	37.6	44.7	52.5	60.9	69.9	79.5
100	4.1	6.3	9.1	16.2	20.5	25.4	30.7	36.5	42.9	49.7	57.1	64.9
	Flow l/min											

Table 5-5 Reaction Forces

Maximum working pressure, bar (ga)		Nozzle diameter, Ø		Maximum working pressure, bar (ga)	
150 N	250 N	flat blade	cylindrical	250 N	150 N
2344	3775	0.8	0.8	2662	1596
1500	2416	1.0	1.0	1704	1020
1042	1677	1.2	1.2	1183	709
667	1073	1.5	1.5	757	453
463	745	1.8	1.8	525	314
375	604	2.0	2.0	426	255
310	499	2.2	2.2	352	211
260	419	2.4	2.4	295	177
214	357	2.6	2.6	249	150
191	308	2.8	2.8	217	130
167	268	3.0	3.0	189	113
147	235	3.2	3.2	166	100

For work inside equipment, reaction forces shall not exceed 150 N.

Table 5-6 Pressure Drop for 10 m Hose

Volume	Pressure drop in bar for 10 metre long hose							
	NW 4 1/8"	NW 5 3/16"	NW 6 1/4"	NW8 5/16"	NW10 3/8"	NW13 1/2"	NW16 5/8"	NW19 3/4"
l/min	Inside diameter of hose							
1000	--	--	--	--	--	815	78	114
800	--	--	--	--	--	522	178	79
600	--	--	--	--	1143	293	107	44
500	--	--	--	--	794	203	74	30
400	--	--	--	--	508	140	47	21
300	--	--	--	909	285	78	28	11
250	--	--	--	631	212	54	20	8
200	--	--	--	404	136	37	13	5
150	--	--	1013	242	76	21	7	3
100	--	--	479	107	36	9	3	1.7
90	--	940	388	93	31	8	3	1.4
80	--	743	306	73	24	6	2	1
70	--	604	234	56	18	5	1.4	*
60	--	444	172	43	14	4	1.2	*
50	982	308	127	30	10	2	1	*
40	628	208	81	20	6	1.5	*	*
30	353	117	48	12	4	1	*	*
20	172	55	22	5	1	*	*	*
10	46	15	6	1	*	*	*	*

* Pressure drop negligible