MANUAL

DESIGN AND INSTALLATION OF CHEMICAL-RESISTANT BRICK LINING FOR PROCESS EQUIPMENT

DEP 30.48.60.13-Gen.

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DESIGN AND ENGINEERING PRACTICE

PREFACE

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APPENDICES

1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for the design, installation, testing and inspection of chemical-resistant brick linings for process equipment.

This DEP is a revision and combination of DEP 30.48.60.13-Gen. dated August 1981 and DEP 30.48.60.23-Gen. dated March 1984, the latter of which is now withdrawn.

The chemical-resistant lining materials shall be in accordance with DEP 30.48.60.33-Gen.

For the design and installation of chemical-resistant linings on concrete structures, reference is made to DEP 30.48.60.12-Gen.

For rubber linings, reference is made to DEP 30.48.60.10-Gen. and DEP 30.48.60.30-Gen.

This DEP does not provide detailed specifications for each case of chemical attack. Each case shall be looked at individually and, based on these minimum requirements, details shall be agreed between the Principal, the Contractor, the Manufacturer and the Applicator.

NOTE: In various places in this DEP specific brands of products are named. It is not intended to preclude the use of other products; equivalent products may be used provided the Principal so approves.

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, 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, chemical plants, gas plants, and, where applicable, in supply/marketing installations and 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

1.3.1 General definitions

For the purpose of this DEP, the following definitions shall hold:

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 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.

1.3.2 Specific definitions

The **Applicator** is the party which applies the chemical-resistant linings specified by the Contractor.

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 (10).

2. GENERAL

A chemical-resistant brick lining is used for the internal protection of process vessels, columns, tanks, etc. against corrosive attack. It is a multilayer system supported by a shell to provide rigidity and strength and, generally, consists of an impervious membrane to prevent the corrosive medium reaching the shell, and one or more layers of chemical-resistant bricks laid in a chemical-resistant mortar.

The lining acts primarily as a corrosion barrier in direct contact with the process fluid. In practice, of course, such a lining will also act as a heat barrier.

A typical brick lining composition is shown in Appendix 7 - Figure 1. The principle of a brick lining relies on each layer of brick, including every joint, being bonded to the next layer so as to form a composite structure with membrane and shell. Therefore great care shall always be taken to avoid anything that might lead to failure of the bond between adjacent layers of brick, or to failure of the bond between the lining as a whole and the wall of the outer shell. Although bricks and mortars are permeable to some extent, the perfect chemical-resistant brick lining prevents corrosion because, in such a lining, there is complete stagnation in the pores, so that the corrosive medium cannot be refreshed and is thus rapidly exhausted.

Brick lining is susceptible to crack formation because of the low tensile strength of ceramic materials, the low bond strength between the mortar and bricks, and the greater thermal expansion of the steel compared with the brick lining. Any crack in the brick lining will allow penetration of the corrosive medium through the lining, which will result in corrosion being sustained.

A safe approach to prevent corrosion of the vessel wall is by the application of a corrosion-resistant and impervious membrane onto the vessel wall prior to applying the brick lining.

The chemical-resistant brick lining should be constructed by experienced applicators to ensure that good workmanship is achieved. A specialised brick lining firm should be responsible for the complete system, i.e. the brick lining plus the membrane.

3. CHEMICAL-RESISTANT LINING MATERIALS

3.1 GENERAL

The various components of a chemical-resistant brick lining are specified in the following sub-sections. Optimum properties will only be achieved if proper attention is given to the installation requirements.

3.2 MEMBRANES

Membranes, or protective interlayers, are of prime importance for the operation and service life of a brick lining.

A membrane need not necessarily be completely resistant by itself, as the brick lining acts as a diffusion/temperature barrier and also prevents free transport and circulation of the corrosive medium to the membrane. This reduces the chance of attack of the membrane.

A continuous and impervious membrane should be used.

If no suitable impervious membrane is available, a brick lining should only be selected provided that there is convincing evidence that a crack-free lining can be applied and maintained, e.g. by prestressing the brick lining.

Membranes must be taken into account when making heat transfer or stress calculations (5.1).

Materials used for membranes in process equipment are listed in Appendix 1, together with an indication of their chemical resistance to some service environments. Rubbers (3.2.1) and polyisobutylene (3.2.2) are best suited to be used as membranes because they adhere well to the synthetic-resin-based cement and permit a high elastic elongation.

A summary of the main requirements for the various membrane materials is given in Appendix 2.

3.2.1 Rubbers

A hard rubber (80° Type D Shore durometer ASTM D 2240) is generally used, but soft rubber (60° Type A Shore durometer ASTM D 2240) or a composite of a hard rubber over a soft rubber is also possible. The minimum thickness of a rubber membrane shall be 5 mm.

Requirements for rubber linings and design and installation of rubber-lined process equipment, piping and concrete structures are given in DEP 30.48.60.30-Gen. and DEP 30.48-60.10-Gen. respectively.

3.2.2 Thermoplastics

The most common thermoplastic membrane material is polyisobutylene which, makes a good liquid-tight membrane. Other thermoplastic membranes are generally too rigid to accommodate irregularities in the vessel wall. The membrane shall be adhesively bonded to the substrate and the joints shall be sealed by welding (6.2.3). The selection of a suitable adhesive depends on the type and condition of the substrate and also on the operating temperature range. Cold adhesives are generally used. No vulcanisation is required. The maximum allowable operating temperature is 70 °C.

The minimum thickness shall be 3 mm.

3.2.3 Thermosetting materials

For specific chemical conditions, glass-fibre reinforced epoxy-resin-based membranes may be used. Epoxy-resin-based materials are generally preferred to other thermosetting resins such as polyester and vinylester because of their good chemical resistance. The technique of lining consists of applying resin and glass-fibre reinforcement alternately.

The selection of type and quality of resin, curing agent, glass-fibre reinforcement, laminate build-up, glass-resin ratio and thicknesses shall be based on the required chemical resistance, adhesion and strength.

The thickness of the membrane shall be a minimum of 3 mm.

3.2.4 Lead

A lead lining is often used as an impervious membrane for brick linings in sulphuric acid service, particularly for sulphuric acid concentrations over 50%.

The lead shall be homogeneously applied in order to achieve satisfactory performance.

A homogeneous lead lining shall be applied to the steel surface in a horizontal position. The best adhesion is obtained when the steel surface has been lightly tinned. The maximum allowable temperature depends on the corrosive environment and the composition of the precoat layer.

Where lead sheets are connected to the wall by bolts, rivets or lead caps, they will sag at relatively low temperature under their own weight and result in tearing off at the supports. In this case the maximum allowable temperature is 70 °C.

The minimum required thickness is 6 mm.

3.3 CHEMICAL-RESISTANT MORTARS

3.3.1 General

Silicate-based mortars or synthetic-resin-based mortars are commonly used to cement the bricks. The chemical resistance of these mortars is not as high as that of the bricks, therefore careful selection is required and a chemical resistance test should be conducted to confirm the resistance of the selected material.

Erosion resistance of the mortars should also be considered.

Appendix 1 indicates the chemical resistance of various mortars and Appendix 3 gives their mechanical and physical properties.

Hydraulic cements are occasionally used for chemically-resistant brick linings in process equipment. Information on these cements is given in DEP 30.48.60.12-Gen.

3.3.2 Silicate-based mortars

Silicate-based mortars are two component systems. They consist of a sodium, or potassium, silicate solution mixed with inert fillers, e.g. quartz flour. The mortar cures as silica is deposited from the alkali silicate solutions, a process which is accelerated by the presence of a catalyst, e.g. salts of fluosilicic acid or dimethylformamide.

When contact with sulphuric acid is expected, potassium silicate-based mortar is preferred to sodium silicate-based mortar (see Note 1).

Mild alkaline media can be tolerated at ambient temperature after careful "acidulation" of the mortar (6.4.2). Alternating acid and alkaline service cannot be tolerated.

Silicate-based mortars have only slight resistance to erosion, especially from flowing hot water, steam or alkalis, and washing out of mortar from the joints may occur. For these services, the use of other types of mortar, mainly synthetic resin-based mortars, shall be considered.

A properly mixed fresh mortar reacts readily and cures even when air is excluded.

Silicate mortars can be used up to about 900 °C.

Silicate mortars do not adhere to rubber membranes.

NOTES:

1. Under these conditions the sodium sulphate formed in the sodium silicate mortar crystallizes with an increase in volume due to the release of crystallisation water. Potassium sulphate, on the other hand, crystallises without increase of volume.
2. Halogen-containing silicate-based mortars may, in contact with strong acids, produce hydrofluoric acid which would attack the substrate on direct contact with it. For such conditions, halogen-free silicate-based cements have been developed.
3. The porosity of silicate-based mortars, which is between 7 and 16% depending on the type, is a major disadvantage and therefore they shall not be used as a membrane.

3.3.3 Synthetic resin-based mortars

Synthetic resin-based mortars are commonly used for the construction of acid-resistant brick linings. They cure as a result of a chemical reaction between the synthetic resin and a curing agent. They adhere very well to a rubber membrane.

3.3.3.1 Mortars based on phenol-furfuraldehyde resin

These mortars consist of phenol formaldehyde resin and furane derivatives with an inert filler. They are supplied as two components, a liquid resin solution and an inert powder (both of which also contain part of the reactive agent), which shall be thoroughly mixed together.

Modified phenolic resin-based mortars have been developed to cover a wider range than pure phenol formaldehyde resin or furane resin mortars. They provide excellent resistance to both acidic and alkaline conditions and have good resistance to mildly oxidizing solutions.

If resistance to hydrofluoric acid is required, only graphite shall be used as a filler.

Generally, for optimal chemical resistance, curing should be conducted for one week at 15-20 °C. Mortars not fully cured can be damaged by moisture and free alkalis which tend to neutralize the acid catalyst.

The time lapse between application and curing shall be defined by the Manufacturer. In order to give the mortar its full chemical resistance it shall be given a heat treatment at 80 °C for 24 hours after it has fully cured.

The temperature limit of these mortars is 180 °C.

These mortars, when properly applied, are erosion resistant and free of pores. They can be used both as a membrane and for embedding and sealing the joints between bricks or tiles.

3.3.3.2 Mortars based on furane resin

Furane resin-based mortars have similar properties to mortars based on phenol resin.

Furane resin-based mortars are supplied as two components (a powder and a liquid) and the mortar has excellent adhesive qualities. It cures at 15-20 °C in about 3 days. Optimum chemical resistance can be obtained by heating at 80 °C for at least 16 hours after application.

Furane resin-based mortars have a good chemical resistance and, with a graphite filler, resistance against hydrofluoric acid can also be obtained.

Furane resin-based mortars are erosion resistant and free of pores.

The temperature limit of furane resin mortar is approximately 220 °C.

3.3.3.3 Mortars based on polyester resin

Mortars based on (unsaturated) polyester resin are supplied in two or more components, i.e. liquid resin, catalyst, accelerator, filler, etc., which shall be mixed together. These mortars have a good chemical and erosion resistance.

The mortar is self-curing at 15-20 °C and at this temperature a complete cure can be obtained in 24 hours. However, for optimum chemical resistance, a longer curing period is recommended. The pot life of polyester-resin-based mortars is rather short and influenced significantly by the temperature.

Addition of inert fillers such as graphite may extend its resistance even to hydrofluoric acid, while resistance against alkalis may also increase.

The operating temperature limit of polyester resin-based mortars is 120 °C.

3.3.3.4 Mortars based on epoxy resin

Mortars based on epoxy resin are supplied in two or more components. Curing starts immediately after mixing and the rate of curing is influenced by the ambient temperature.

Properties will vary according to the various curing agents used. The curing agent generally used is a cold-curing type, which limits the maximum operating temperature but facilitates processing.

Epoxy resin-based mortars have very good chemical resistance. If a filler such as graphite is added, resistance to hydrofluoric acid is also obtained. Epoxy resin-based mortars also have very good adhesion. Apart from proper surface cleaning, the substrate needs no further pre-treatment.

In metallic process equipment these mortars can be used as membranes, with an optional glass-fibre reinforcement.

The temperature limit of epoxy resin-based mortars is 90 °C.

3.4 CERAMIC LINING MATERIALS

3.4.1 General

Bricks and tiles manufactured to standard dimensions should be used whenever possible to avoid additional costs. If special shapes are used, detailed drawings shall be made to indicate their position in the lining.

Radial bricks are required when the width of the side joint at the back of the standard brick would be greater than 1.5 times the joint width at the front of the standard brick.

Console bricks are sometimes used in the inner course of bricks to support internals.

The bricks and tiles shall have a roughened surface and shall not be glazed, to ensure good adhesion to the cement.

Mechanical and physical properties of various chemical-resistant lining materials are given in Appendix 3.

Porous bricks offer low resistance to penetration of liquids and/or gases. They have high thermal conductivity and good thermal shock resistance. Porosity needs to be considered, particularly in the case of crystallising liquids where there is a potential danger of volume change destroying the brick. Due to the low thermal conductivity, high thermal gradients can occur in the bricks. Temperature shock(s) can lead to thermal spalling.

The erosion resistance of the bricks and tiles shall also be considered.

Most brick and tile materials have good resistance to organic chemicals, so their resistance to inorganic chemicals often governs the final selection.

3.4.2 Acid-resistant bricks and tiles

Silica-alumina acid-resistant bricks with a maximum apparent porosity of 5%, as specified in DEP 30.40.60.33-Gen., are widely used in chemical-resistant brick linings. Higher apparent porosity e.g. 12% produces increased thermal shock resistance but reduced chemical resistance.

Small variations in the chemical composition of the bricks can produce significant changes in their chemical resistance and mechanical properties. For example, enhanced properties are achieved by the addition of oxides of iron, titanium, magnesium, potassium and sodium. The Al_2O_3 content, which generally varies between 15 and 30%, can be used to vary the acid resistance of the bricks. In some countries, e.g. USA and UK, less resistant bricks are produced containing more than 30% Al_2O_3 but the Al_2O_3 content may be reduced to below 10% where increased acid-resistance is required.

Further control of the mechanical and chemical properties of the bricks can be achieved by varying the firing times and temperatures used to control the ratio of glassy to crystalline phases in the bricks, or alternatively by varying the structure and distribution of the grains of the constituent materials. For example, acid-resistant bricks with an apparent porosity of 5% can resist all acids except hydrogen fluoride and alkalis up to concentrations of 20% weight at room temperature. Carbon or graphite bricks, or porcelain tiles are required for resistance to higher concentrations of alkali.

3.4.3 Porcelain tiles

The chemical composition of porcelain tiles is similar to that of acid-resistant bricks, but the raw materials are purer and ground finer. Porcelain is fired at about 1400 °C instead of 1100-1200 °C as for bricks.

The high density, and the composition virtually free of impurities, results in a product which is preferred for those cases where the porosity of the acid-resistant brick could lead to spalling. The high mechanical strength imparts high resistance to wear.

Typical applications are acid service (e.g. H_2SO_4) and erosive service (high speed or liquids with solid particles).

Porcelain tiles are generally used only for the surface layers of a brick lining, although the application of graphite bricks for this duty is increasing.

3.4.4 Carbon and graphite bricks

Carbon bricks are made from synthetic carbon.

The raw materials anthracite, soot and petroleum coke are mixed with coal tar, shaped and then fired at 1000-1400 °C to make carbon bricks.

Graphite is made by additional firing of carbon bricks at a temperature of 2700-2800 °C, resulting in a pure crystalline material.

In non-oxidizing atmospheres carbon and graphite can be used up to high temperatures and their chemical resistance is excellent. Carbon bricks are generally available in two qualities, either with an ash content of about 6% or with an ash content below 1%. The latter shall be used when the process liquid contains HF fluorine-containing products or strong alkalis.

Both carbon and graphite are porous but, although rarely done, they can be made liquid tight by impregnating them with synthetic resins during the manufacturing process. Impregnation does not significantly change the thermal conductivity of the materials, but does improve its strength.

Carbon has a moderate thermal conductivity and is very hard. These properties make it an excellent material for corrosive and erosive services with high thermal loads. In these cases the unimpregnated carbon may be used, because mortars and membrane will effectively protect the substrate. Graphite is used when high thermal conductivity is needed.

3.4.5 Special ceramic lining materials

For certain services it may be necessary to select special ceramic lining materials for their high corrosion, abrasion and thermal shock resistance, and high thermal durability.

These ceramic lining materials are mainly based on:

- sintered alumina (Al_2O_3 > 80%)
- silicon carbide (SiC), or
- silicon nitride (Si_3N_4)

3.5 HANDLING AND STORAGE OF LINING MATERIALS

The packaging shall be clearly and indelibly labelled, indicating the name, quality and quantity of the contents.

Bricks and tiles shall be carefully handled, unloaded and stacked by hand or by using brick tongs in accordance with the Manufacturers instructions for safe handling.

The mortars shall not be stored longer than the period indicated by the Manufacturer, generally about 6 months. After this period their use shall be permitted only after a new and complete quality control in accordance with this specification. Mortars from different manufacturers shall never be mixed; labels indicating the name, quality and quantity of the contents shall not be removed.

In cold climates materials may freeze, and they shall be conditioned before use by means of storing in a warm place.

Skin contact with synthetic resin-based materials shall be avoided. Applicators shall observe strict personal hygiene and care when handling these materials in the uncured liquid state. Skin contact should be prevented by using rubber gloves and barrier creams, and any accidentally contaminated skin areas should be thoroughly washed with soap and water and the Manufacturers instructions shall be followed.

4. REQUIREMENTS FOR EQUIPMENT TO BE BRICK-LINED

4.1 GENERAL

The stress-bearing shell, also called "substrate", of every piece of process equipment to be brick-lined shall satisfy a number of requirements additional to those required by the code to which the shell is designed. Those requirements are specified in this section.

Any pressure testing of the shell as required by the design code shall be carried out prior to the application of the brick lining.

The equipment shall be easily accessible and be suitable for chemical-resistant brick lining. Conditions such as pressure or vacuum, cooling or heating, insulating, etc., do not constitute a limitation for brick linings.

The minimum diameter which can effectively be brick-lined is 600 mm working space. Smaller diameters to be lined shall be prefabricated in short sections and assembled with flanges.

The contractor responsible for the brick lining shall ensure before commencement that the specified lining thickness, together with the required final internal dimensions (after lining), can be realized and that the dimensions of the object to be brick-lined are correct.

4.2 PREVENTION OF DEFORMATION

Since the brick lining is susceptible to cracking, the equipment design shall be sufficiently rigid to prevent deformations.

The following measures shall be addressed in achieving the necessary rigidity:

- The equipment wall thickness shall be sufficient not only for pressure containment but also for rigidity.
- The maximum deflection due to wind load shall not exceed $\frac{H}{50}$
- The mass of the brick lining, including packing bed, contents, etc. shall be taken into account. The mass can be estimated as follows:
  - ° Equipment with diameters up to 3000 mm, operating at pressures up to 3 bar and temperatures up to 100 °C, should be designed for an additional stress of 25-30 N/mm^2.
  - ° Equipment with diameters greater than 3000 mm, operating at pressures up to 10 bar and temperatures up to 200 °C, should be designed for an additional stress of 30-50 N/mm^2.
  - ° For operating conditions above 10 bar and 200 °C, each application should be considered separately.

The following measures, aimed at avoiding stress concentrations, will reduce the likelihood of local deformations:

- Use cylindrical vessels.
- Use vertical vessels supported on skirts with the same diameter as that of the vessel shell. Legs should not be used instead of skirts.
- If horizontal vessels are unavoidable, use extra wide saddles or longitudinal supports of sufficient rigidity.
- Use hemispherical heads, or other types of head with generous knuckle radii, in preference to flat heads. Atmospheric storage vessels with flat bottoms can be brick-lined but the temperature decrease over the brick lining shall be kept small, since a cooler bottom causes lifting of the brick lining. Welding the bottom plates to the supports can prevent buckling of the steel bottom.
- Avoid sudden changes in wall thickness. Where a change in wall thickness occurs, the internal surface shall be flush (Appendix 5 - Figure 1).

- Avoid external stiffening rings or bars attached to the vessel, and avoid internals connected directly to the shell.
- Connections for stairs, supports, etc., shall be made before the brick lining is applied, since welding afterwards will damage the chemical-resistant brick lining.
- Minimize the number of nozzles, manholes, etc., by combining as many of these as possible into one manhole cover. Nozzles shall not protrude into the inside of the vessel, but should be welded either in the corner or onto the bulged-out vessel wall (Appendix 5 - Figure 2). Belled-out nozzle openings should be used whenever possible for vessels operating at higher pressures.
- Specify tolerances in accordance with DIN 28060 Bbl 1 or DEP 31.22.10.32-Gen., with the following amendments:
    - ° Out-of-roundness (difference between maximum and minimum internal diameters) shall be maximum 0.2% (for all diameters).
    - ° Joint alignment: misalignment measured at the surface of the plates before welding shall not exceed 5% of the plate thickness plus 1 mm with a maximum of 1.5 mm for the longitudinal joints and a maximum of 2.0 mm for the circumferential joints.
- Avoid transporting a brick-lined vessel or section.
- Ensure the vessel is shielded from rain or solar radiation, both during installation and service.

4.3 LIQUID TIGHTNESS

The steel vessel shall be liquid-tight, as confirmed by the hydrostatic pressure test according to the applicable vessel design code, prior to applying the membrane or the brick lining.

4.4 SURFACE CONDITION

If the vessel to be brick-lined is to have a membrane, the requirements for the internal surface condition of the shell shall be governed by the application of the membrane.

Air inclusions can be prevented as follows:

- Avoid designs with head curved to the inside (Appendix 5 - Figure 3).
- Provide for correct weld design:
    - ° Preferably locate welds in the cylindrical part of the vessel, see Appendix 5 - Figure 4. If this is not possible, then the corner may be made with a profile giving a weld in the cylindrical part and in the bottom; an extra leg may be included to guide rainwater, etc., see Appendix 5 - Figure 5.
    - ° For butt-weld cone-shaped ends or bottoms, the welds may be made in the corner provided they are finished smoothly, see Appendix 5 - Figure 6.
    - ° If corner welds cannot be avoided, air-escape holes shall be applied.
    - ° V-welds made from the inside are preferred.
    - ° Sharp edges, weld spatters, etc., shall be removed.
    - ° Welds shall be in-line and shall be finished smoothly.
    - ° Internal changes shall be rounded with a radius of at least 3 mm, but preferably 5 mm.

For further requirements for rubber-lined equipment, see DEP 30.48.60.10-Gen. and DEP 30.48-60.30-Gen.

5. DESIGN AND CALCULATION OF CHEMICAL-RESISTANT BRICK LININGS

5.1 GENERAL

The brick-laying Contractor should provide a temperature curve and a stress curve for each layer of the brick lining, to confirm that the maximum temperature and allowable stress valves are not exceeded. See Appendix 4.

Guidance with respect to the calculation is given in Matz and Füller's handbooks.

5.2 THICKNESS OF THE BRICK LINING

The thickness of the brick lining is determined by the number of layers of bricks, by the dimensions of the brick and by the lay of the brick within the layer.
When the brick lining functions as a heat barrier, the minimum thickness is determined either by the maximum permissible membrane temperature (Appendix 4), by the steel wall temperature (maximum 100 °C), or by the maximum temperature gradient of the brick.

In general, a lining will comprise two layers of bricks staggered, the layers overlapping both horizontally and vertically. See Appendix 6.

This arrangement is suitable for severely corrosive conditions, although for 90 °C hydrochloric acid service good results have been obtained with one layer of carbon bricks laid radially. At higher temperatures this may cause spalling.

Too thin a lining may crack open and tear away, because of high stresses due to internal pressure and thermal gradient, even when mortars with swelling properties are used (5.4).

Too thick a lining may result in spalling and crushing of the weaker adjacent layer, because of high thermal and tensile stresses (5.3).

5.3 OTHER DESIGN DETAILS

- Linings for large flat surfaces will need to be thicker than curved surfaces, as a curvature contributes to the overall strength.
- It will be necessary to provide supports where the lining cannot be supported by the contour of substrate, except where the mass of the brick lining is low enough to rely on the adhesion of the cement.
- Inaccurate shaping of the substrate will cause unacceptable local compressive stresses and buckling of the brick lining.
- Stirred vessels or vessels with flat bottoms shall have shaped bottom linings made from straight bricks. The vessel wall lining should not rest on the bottom lining unless more than two layers are applied, see Standard Drawing S 10.110.
- Typical construction details of vessel flanges, manholes and nozzles are given in Standard Drawings S 10.111, S 10.112 and S 10.113. Direct passage to the vessel wall is avoided as much as possible.
- Internals shall not be directly supported by the vessel wall through the brick lining. Instead, they shall rest on the brick lining by means of console bricks (Appendix 7 - Figure 1). Supporting grids for an internal packing bed can be made from corrosion-resistant metal or alternatively fabricated in situ from ceramic elements, such as Koenig's grid as shown in Appendix 7 - Figure 2.

  Metal grids are easily removable. Their disadvantages are vulnerability to mechanical damage by shock or concentrated loads, the rather low free passage area and, especially for larger diameters, the low load-bearing capacity.

  Ceramic element grids can be used for large diameters providing high load-bearing capacities with good free passage areas. Their disadvantages are that the vessel needs to be divided into different parts, sometimes requiring extra manholes, and because of the large openings, intermediate layers may be needed, e.g. for stacked rings followed by dumped rings. The necessity to support the grid during construction and hardening of the mortar joints also needs to be considered.

Internals independent of the lining, such as inlet pipes, spray nozzles, distribution trays, hold-down trays, etc., shall be installed such that they do not impede thermal movement of the brick layers, either by resting on them or by being locked into the brick lining. They shall be fabricated from material with appropriate chemical, thermal and mechanical properties. See Standard Drawing S 10.112.

5.4 EFFECTS DUE TO THE SERVICE CONDITIONS

The design of brick linings shall be such that the thermal, chemical and mechanical effects from operation do not cause cracks.

Thermal effects may be caused by:

- heating or cooling of the contents or the equipment, or by the heat of reaction the range of operating temperature, or the rate of change of temperature fluctuations;
- insufficient external insulation.

Chemical effects are dependent upon process conditions such as:

- concentration, temperature, sequence of addition;
- stream velocity;
- presence of impurities.

Mechanical effects, both static and dynamic, could result from:

- mass of contents;
- internal pressure;
- influence of mixers, etc.;
- erosion;
- supports.

The brick lining shall be constructed such that the lining does not tear away from the vessel wall.

Since the coefficient of thermal expansion of steel is about twice that of the brick lining, the steel shell will tend to expand more than the lining and thus introduce tensile stresses in the lining, an effect which is increased by internal pressure. Since the tensile strength of brick and mortar is low, as is the bond strength of mortar, cracks could develop unless special precautions are taken (5.5).

With low operating temperatures, benefit can be derived from making the lining thicker so that the expansion of the steel shell is equal to that of the outer layer of bricks, or to the average expansion across the brick lining.

At higher operating temperatures, tensile stresses may become excessive and a correspondingly thick brick lining would add much to the cost. In practice, good results are obtained with relatively thin brick linings, because of:

- the membrane, having a low heat conductivity to keep the steel shell temperature low, and a high coefficient of thermal expansion to compensate for the difference in thermal expansion between steel shell and brick lining. The maximum allowable temperature for the membrane shall not be exceeded;
- the curing and pre-stressing effect of the mortar (5.5);
- the application of only a thin external insulation layer to maintain the temperature at the brick lining/membrane interface up to the lowest possible.

Alternatively, the high tensile stresses in the brick lining can be reduced by raising the temperature of the steel shell to about 40 °C during the application of the brick lining either by blowing in hot dry air or heating externally be means of electric heating cables.

5.5 PRESTRESSING AND CURING OF MORTAR

If, before the mortar is fully cured, brick-lined equipment is heated and pressurized under controlled conditions, the mortar will plastically deform, and the brick lining will follow the movement of the shell. If conditions are maintained long enough, the mortar will cure in the expanded condition and will not plastically deform on cooling down.

After completing this treatment of swelling and pre-stressing, the shell will contract around the brick lining. This applies a compressive stress to the lining, and the shell remains under a little tension. If the pre-stressing is performed under the intended process operating pressure and temperature, the lining will become almost stress free during normal operation.

This treatment needs to be applied before the mortars have cured completely, but the curing reaction needs to have progressed to a point where the mortar will not 'flow' at increased temperatures. Therefore, unless special precautions are taken, pre-stressing should not start within less than 8 days after bricklaying has been finished, but no later than 6-8 weeks after bricklaying has started.

The mortars used can be either silicate-based or synthetic-resin-based. Heating and curing will be optimal when they are in contact with a liquid. The liquid shall have high heat transfer properties, but shall have no detrimental effects on the mortars. An acidic liquid is preferred.

Throughout the curing period prior to pre-stressing, the mortars shall be protected against moisture. This can be done by blowing in hot dry air.

Synthetic-resin-based mortars pass through a high elongation zone at about 100 °C. When pre-stressing is to be applied, it is recommended to apply the maximum pressure at this temperature in order to obtain the maximum possible deformation.

For determining the conditions and the chemicals to be used appropriate to the correct procedure for each application, the Principal shall be consulted.

To obtain good chemical resistance, the mortar should be completely cured.

6. INSTALLATION

6.1 GENERAL

Bricks and tiles should be stored near the job under temperature conditions as specified in (6.1.1) for approximately 48 hours prior to use, to avoid temperature and humidity changes during the execution. Before installation, a thorough inspection of the condition and cleanliness of the surface to be lined shall be carried out, the bricks and tiles shall also be clean.

Adequate ventilation shall be provided for the application of solvent-containing materials. For the handling of chemical-resistant lining materials, see (3.5).

Brick-lined equipment should be installed such that a complete inspection of the outer surface is always possible. Flat-bottom steel vessels shall therefore be supported on beams so that an inspection of the bottom can be made.

When installing pre-lined sections, e.g. ducting, mortar shall be placed on the upper layer of closing bricks, which shall have been carefully laid to form a smooth and even surface for flanged connections. These flanged connections shall be made while the mortar is in the wet condition applying only half the normally required force on the bolts, which shall be fully tightened after curing. For severely corrosive conditions, a PTFE sheet should be cemented into position to cover and protect the joint. Alternatively, a special male/female flange connection shall be made, particularly when a membrane is applied, see Standard Drawing S 10.113 Type C.

6.1.1 Temperature

The temperature of equipment to be brick-lined should be maintained between 18 and 22 °C. Higher and lower temperatures will influence the correct curing of the mortar. When the equipment to be lined is at a temperature above 22 °C, the mortar shall be mixed in small quantities in some other location and kept between 15 and 20 °C before use. Temperatures which are too high impair the 'pot life' of mortar.

For conditions below 15 °C, the equipment temperature should be raised, preferably by electric heating to avoid uncontrolled moisture development. Painting of the outside surfaces of equipment with a high-reflecting white coating will reduce the uneven heating effect of the sun. A light-weight shield will reduce the effects of sun, rain and wind on the surface.

6.1.2 Humidity

Condensation is not allowed on the substrate, the membrane and installed layers of the lining. The substrate temperature shall therefore always be at least 3 °C above dew point; relative humidity shall not exceed 85%.

The surface temperature and relative humidity of the air shall be controlled by electric heaters and air drying equipment. A daily record of the working conditions shall be kept. Cement shall remain free from contact with water and vapour.

6.2 INSTALLATION AND INSPECTION OF MEMBRANES

6.2.1 General

Membranes shall be continuous, liquid-tight and sufficiently flexible. Proven installation procedures and careful application are necessary. The liquid tightness shall be tested after installation; the procedure and test equipment shall be approved by the principal.

If there is mill scale, rust or other contaminants, the metallic substrates shall be blast-cleaned to Sa 2 in accordance with ISO 8501-1.

When applied on a metal substrate, non-conducting membranes shall be holiday tested in accordance with ASTM D 5162. For anti-static linings, the low voltage wet sponge method shall be used.

The membranes shall also be visually inspected for air inclusions (blisters), cracks or other imperfections.

6.2.2 Lead

See also (3.2.4).

For the adhesion of lead to a steel substrate, the steel surface shall be lightly tinned with a 0.02 to 0.05 mm thick layer which shall be free from pores. To obtain good adhesion, dirt, grease and rust shall be removed thoroughly by blast cleaning or by etching with hydrochloric acid, within 24 hours prior to application of the tin.

The installation and testing of lead membrane linings shall be in accordance with DIN 28058. The tightness of the lining shall be verified with the 'sulphuric acid indicator test'. For this purpose the lead surface is primed with a solution of 20% sulphuric acid which is washed away with clean water after 3 hours. Any pores in the lead lining will remain filled with the acid solution. If a mixture of water and 'Congo red', having a pH indicator in the range 3 to 5, is then applied and allowed to dry, the pores will show up blue against the red surface.

The minimum thickness of a homogeneous lead lining shall be 6 mm. The tolerance on the specified thickness shall be minus zero and plus 25%.

The thickness can be checked with a magnetic layer thickness meter (non-destructive), or by measurement after locally melting the lead (destructive).

Poor adhesion of the lining will reduce the heat conductivity, which could lead to further detachment of the lead lining due to temperature changes and pressure/vacuum variations during operation. The adhesion shall be ultrasonically tested from the outside (steel) side of the equipment, using samples of both correctly bonded and poorly adhered test pieces for interpretation.

6.2.3 Thermoplastics

See also (3.2.2).

The installation shall be in accordance with Manufacturer's instructions, generally as follows:

The thickness shall be 3 mm minimum. Sheets could be supplied with a thickness less than 3 mm, in which case they shall be glued together to form sheets of a thickness of minimum 3 mm thickness. The polyisobutylene sheets of 3 mm minimum required thickness are attached to the substrate with an adhesive (glue), the separate sheets and the substrate are both coated with the adhesive but the overlap of the sheets to be joined, 30 mm wide approximately, shall be kept free from adhesive.

After about one hour, but within 12 hours depending on temperature and type of adhesive, the sheet of membrane material will be ready for sticking on to the substrate. To avoid air inclusion, the sheets shall be positioned from the centre to the sides using a suitable wooden tool to avoid damage; preheating of the sheets will facilitate their installation.

The separate sheets should then be joined at the overlap by welding in accordance with the Manufacturer's instructions, generally by roughening with sand paper, cleaning the weld areas with a suitable solvent and welding with hot air welding equipment, the air being directed by a tapered mouthpiece at a temperature between 300 and 350 °C. When the surfaces become soft they are pressed together with a roller and the seam should almost disappear. Vertical seams shall be welded and rolled downwards to release any remaining solvent.

For severe chemical conditions, the weld seams should be reinforced by welding an additional strip over the completed seam.

For equipment with angular corners the membrane should be reinforced with a welded, corner-shaped patch, covering a small triangle on all three sides forming the corner, which is stuck and/or welded over the membrane.

Small damaged parts of the membrane can be repaired by welding patches of the same material over the spot. Larger damaged parts of the membrane should be removed and the substrate cleaned, after which a new piece can be inserted with adhesive and welded to the surrounding material.

Thermoplastic membranes shall be holiday tested (6.2.1) and there shall be no holidays.

Checking adhesion by careful knocking on the surface can be difficult. Therefore testing after installation may be carried out by filling the equipment with water and raising its temperature during a period of 24 hours to 70 °C. After draining, imperfections in the adhesion will be seen as blisters or bulges on the surface of the lining.

6.2.4 Thermosetting material

See also (3.2.3).

The thickness shall be 3 mm minimum.

Dosing and mixing of the epoxy resin components and installation of the subsequent layers of resin and glass fibre shall be done in accordance with Manufacturer's instructions.

The clean prepared substrate surface shall first be primed with the selected epoxy resin.

The laminate shall be applied 'wet-in-wet', any resin layer that is allowed to cure completely shall be lightly blast-cleaned or roughened with sand paper before the next layer of the laminate is applied. Resin and glass fibre are applied to the surface and the resin is evenly distributed by rolling and pressing, the glass-fibre reinforcement is wetted through completely until all air is removed.

The glass fabric reinforcement shall have an overlap of between 25 and 50 mm.

Mixing equipment shall be calibrated for the quantity of components to be mixed; dosing and mixing shall be carefully carried out in accordance with the manufacturer's instructions.

To prepare for good adhesion of the brick lining to the membrane, the final and sealing layer of thermosetting resin should be dusted or sprayed with silver sand.

Glass-fibre reinforced thermosetting membranes shall be inspected to confirm that there are no:

- dry spots
- inclusions (sand, dirt, etc.)
- blisters
- holes and pores
- delaminations
- resin-rich spots
- stars (mechanical damages)
- crazing (small cracks in or under the surface)
- glass fibres in and through the surface.

A reference laminate shall be prepared in advance, based on the required design criteria.

Test laminates made during the installation can be compared with the reference sample to obtain reliable quality control. The intensity of this inspection shall be related to the quality standard required. For more details of glass-fibre-reinforced epoxy laminates, reference is made to DEP 70.51.10.11-Gen.

6.2.5 Rubber

Rubber linings shall be installed in accordance with DEP 30.48.60.10-Gen.

6.3 INSTALLATION OF BRICKS AND TILES

6.3.1 General

To prevent damage to the bottom membrane, the brick lining of the bottom shall be finished first. Brick linings in vertical equipment are built up ring upon ring with the bricks placed tightly against the wall or membrane. The brick lining for horizontal equipment should, if practical, be installed with the cylindrical part of the equipment placed in a vertical position.

For linings consisting of more than one layer of bricks or tiles, the joints of the layers shall be staggered (Appendix 6).

Normally the same mortar is used for bedding against the membrane and for the radial and circumferential joints. Wedges shall be used for joints which are to be filled later with a different mortar. The installation rules are equally applicable to all types of bricks and tiles.

6.3.2 Joints

Joints between the bricks of chemical-resistant brick linings shall be as small as possible to obtain good strength and resistance. The joint spacing given below shall be strictly observed.

TYPE OF MORTAR	**TYPE OF JOINT**		
	Bed joints	Radial and circumferential joints	Special joints (to be filled afterwards)
	REQUIRED SPACING		
Silicate-based	5 mm, maximum 8 mm	3 mm	7 mm
Synthetic-resin-based	5 mm, maximum 8 mm	5 mm*	7 mm, joint depth 15 mm

* For pre-stressed constructions the design instruction for radial joints shall apply.

Air inclusions in the mortar shall be prevented. The mortar should be placed on the brick being laid as well as on the surface to be lined, and when the same mortar is used for bed, axial and circumferential joints, against the side of the installed bricks. The joints are then filled with the positioning of the brick to achieve a homogeneous filling of joints, the surplus mortar being removed immediately.

6.3.3 Curing

When curing with hot dry air is to be applied, see (6.5.2), the curing process for steel vessels can be started during installation of the bricks as follows:

The metal wall temperature should be maintained as high as possible, i.e. at approximately 35-40 °C, during the installation of the brick lining. To avoid obstruction of the lining work and so as not to influence the pot life of the mortar, heat should be applied on the outside of the metal walls. Drying of the bed mortar layer shall be controlled so that it does not harden too quickly.

6.4 APPLICATION OF CHEMICAL-RESISTANT MORTARS

6.4.1 General

Dosing and mixing of components shall be strictly in accordance with the Manufacturer's instructions.

Different types or qualities of mortars shall never be mixed. Mixers and tools shall be kept clean and dry to prevent contamination of the mortar.

6.4.2 Silicate-based mortars

The mortar is prepared by the addition of the powder into the liquid component during mixing. The addition of water or other products is not permitted. Minor deviations of the mixing ratio are acceptable for improvement of the processability. The prepared quantity shall be used within 20 minutes to avoid disturbance of the curing process.

Four days after completion of the brick lining application, the lining shall be washed with dilute acid, e.g. a 10% wt solution of hydrochloric acid. This treatment ("acidulation") is important, since the alkali hydroxide formed during curing is detrimental to the joint and would eventually destroy it. Filling the equipment with dilute acid is preferable to brushing the joints.

6.4.3 Phenol furfuraldehyde-based mortars

The liquid and powder components shall be thoroughly mixed to a plastic consistency immediately before use. Any water produced during mixing shall be removed.

Curing will commence after 1 to 4 hours at approximately 20 °C, during which time the mortar shall not be touched.

Heat treatment at 80-100 °C during 24 hours is required for complete curing of the mortar.

Contact with water and/or water vapour during curing shall be avoided. Heating shall be carried out by electric heaters, not by direct oil or gas-fired air heaters.

When applying the mortar directly onto steel, the surface must be pre-treated with an appropriate coating to prevent the acidic curing agent corroding the steel substrate. For this so-called adhesion layer, phenolic-based coatings are generally utilized. Such an adhesion layer is not required when using a liquid-tight membrane.

When phenol-furfuraldehyde-based mortars are to be used only for joints between bricks, the faces of the bricks shall be cleaned with a 20% of alcoholic hydrochloric acid solution. The faces shall then be dried and pre-treated by brushing on a coating of the mortar before completing the joint.

6.4.4 Furane-resin-based mortars

Except for the heat treatment which is not required for furane based mortars, the same precautions and guidelines as given for phenol-furfuraldehyde resin (6.4.3) are applicable.

6.4.5 Polyester-resin-based mortars

Dosing and mixing are critical for this mortar. The curing starts quickly, and therefore the resin, accelerator, and filler shall only be mixed immediately before use. Heat treatment is not required to cure the mortar.

The fluidity of the viscous polyester resin varies with the amount of styrene monomer added. The addition of styrene monomer shall be restricted because too much has an adverse effect on the shrinkage, chemical resistance, and mechanical properties of the mortar.

6.4.6 Epoxy-resin-based mortars

The fast curing properties necessitate mixing immediately prior to use of the mortar. Processability is improved with a cold curing agent which, however, limits the temperature range for application of the mortar.

6.5 SPECIAL TREATMENTS AFTER INSTALLATION

6.5.1 Prestressing

Chemical-resistant brick linings are susceptible to tensile and bending stresses. Proper curing and pre-stressing should result in compressive stress in the brick lining while the substrate remains under little tension. Pre-stressing (5.5) can be used to achieve this and should be applied whenever possible.

To obtain good chemical resistance the mortar shall be completely cured.

6.5.2 Pre-stressing with acidic liquid

Pre-stressing with acidic liquid is a wet curing process suitable for brick linings operating above 80 °C and 1 bar (ga) under severe chemical conditions. Considering the time limits (5.5), the vessel is either filled with acidic liquid or the liquid is circulated. The liquid is heated to raise the wall temperature up to the operating temperature gradually, while the pressure is raised to the maximum operating pressure.

Circulating liquids shall thoroughly wet all parts of the brick lining and, after maintaining the operating conditions for several hours to cure the mortar completely, the temperature and pressure shall be slowly reduced to ambient, see (6.5.4).

6.5.3 Curing liquids

Manufacturers instructions shall be adhered to. In general, diluted acids are used for curing. A solution with a pH value between 2 and 5 is recommended for synthetic-resin-based mortars.

For silicate-based mortar, a 5 to 10% solution of sulphuric acid is suitable; hydrochloric, phosphoric or acetic acid solutions are also acceptable.

Solutions of calcium chloride, sodium bisulphite or calcium bisulphite should not be used for silicate-based mortars as insoluble salts are deposited. Such deposits should be removed by a separate wash treatment.

The curing liquid is brought to the required concentration at ambient temperature in a separate vessel of rubber-lined, thermoplastic or glass-fibre-reinforced plastic material, and the liquid is then pumped or circulated to the equipment, see Appendix 8.

For equipment that will operate under pressure, a curing liquid pressure of 0.5 bar (ga) is required.

The liquid temperature should be raised at a rate of 5 to 7 °C per hour up to the operating temperature with steam injection (direct or via a sparger) or by circulation through a heat exchanger. To limit expansion of the lining during heating, the temperature differential in the equipment should remain within 15 °C. The pressure shall be raised simultaneously with the temperature to reach the required operating pressure at about 100 °C.

The final curing condition shall be maintained for 72 hours, followed by cooling at a rate between 3 to 5 °C per hour whilst gradually reducing the pressure. By controlling the cooling rate, it shall be ensured that the rate of metal wall shrinkage is not less than that of the lining material. Boiling of the liquid shall be prevented by controlling the ratio between pressure, temperature and liquid concentration. After cooling to ambient conditions the vessel shall be left for 3 hours with the circulation on, and then - after draining and washing - the lining shall be inspected.

The following data shall be recorded during pre-stressing and curing:

Temperature	-	liquid in equipment or liquid inlet and outlet temperature
	-	metal wall temperature at 3 representative points
	-	ambient temperature
Pressure	-	inside the equipment

NOTES: 1. Steam injection direct or via a sparger is in general more economical compared with a heat exchanger circulation system. Heating with open steam will dilute the liquid, raising the pH value. Addition of fresh liquid will be required to maintain the pH value below 5. The surplus of the used solution shall be removed from the curing process.

2. The lining contractor shall provide a calculation showing the stresses expected during pre-stressing and curing.
3. Drain and washing fluids shall be disposed of in a controlled and approved way.

6.5.4 Curing with acidic liquid

Curing with acidic liquid is applied for brick linings operating at ambient temperature. Considering the time limits (5.5), the vessel is filled with an acidic liquid (7.1.3) and after 3 weeks emptied, water-washed and inspected.

6.5.5 Curing with dry hot air

Curing with dry hot air is applied for brick linings operating at conditions up to 80 °C and 1 bar (ga). The curing should preferably begin with application of heat at the installation stage, see (6.3.3).

Considering the time limits (5.5), dry hot air is introduced in the bottom of the dry and closed equipment. To control proper curing of the mortar, especially during the initial period, direct flame heaters should not be used. The air temperature shall be raised at 5 to 7 °C per hour and the pressure shall be increased simultaneously to the intended operating pressure.

The final curing condition shall be maintained for 16 hours, followed by cooling at a rate of 3 to 5 °C per hour whilst simultaneously reducing the pressure. After arriving at ambient temperature and pressure, the brick lining shall be inspected.

7. OPERATION

7.1 GENERAL

To ensure long service life for brick-lined equipment, careful supervision throughout construction, pre-stressing and curing is essential. The initial start-up period is critical, so precise operator control is also essential.

Surveillance during normal operations shall be logged as an established routine.

Brick-lined equipment shall not be put into operation before the mortar has been fully cured.

7.2 START-UP

The initial start-up of brick-lined equipment shall be carried out under carefully controlled conditions. Accurately written operating instructions shall be established, based on information to be supplied by the brick lining contractor for equipment with critical limitations of temperature and pressure during start-up and/or operations. The expansion of metallic substrates under the influence of internal pressure and temperature is generally larger than that of the brick lining. Without strict control, this expansion and the rate of expansion may cause cracking of the lining as well as loosening from the surrounding shell, which are both unacceptable. Heating and pressurizing shall therefore be carried out at such a rate that expansion of the metal wall is, at any given moment, smaller than that of the brick lining.

7.3 ACTUAL OPERATION

Brick-lined equipment shall be heated and cooled down slowly to prevent loosening of the brick lining from the vessel wall, causing cracking of the lining and back-flow of products. Also, the low thermal conductivity of the brick lining causes high temperature gradients over the thickness of the lining, which could result in cracking and spalling the bricks if the heating and cooling down is not controlled.

This applies particularly to hot or cold liquid jets directed into the lining. Liquid jets shall either be adjusted in direction or fed to the vessel under a liquid level. Steam jets are not allowed because of risks of spalling of the bricks.

Pressure shall be raised and lowered slowly to prevent loosening of the brick lining from the wall.

When silicate mortars are used in the joints of the top layers, no liquid streams shall be allowed to flow at high speed along the surface of the lining because the mortar will be washed out of the joints.

The operating conditions as set during the design shall be adhered to.

If a change in operating conditions is envisaged, the effects of chemicals, temperature, pressure and a combination of three shall be carefully studied.

8. TRANSPORT OF BRICK-LINED EQUIPMENT

To prevent cracking, deformation and disbonding caused by shock or vibration to the rather brittle lining materials, the equipment should not be transported or handled after the brick lining is installed. Equipment to be brick-lined should be properly installed before the lining is applied.

If transport and handling of brick-lined equipment or parts thereof, e.g. small vessels, pipe sections, ducting, etc., cannot be avoided, the design and execution shall make allowance for more rigid construction, adequate lifting points, additional internal and external supports, and temporary studs for rigid fixing during transport. The equipment shall be completely cured and pre-stressed before handling.

In the case of unforeseen moving of equipment, stiffening rings or structures shall be designed and applied. However, welding on lined equipment should be avoided wherever possible.

9. INSPECTION AND MAINTENANCE

9.1 INSPECTION

The equipment shall be inspected by experienced personnel, in accordance with this manual.

Equipment to be assembled from parts shall be checked for correct assembly, before installation of the lining.

Test pressures for brick-lined equipment shall be limited to 10% above the operating pressure, to prevent unacceptable deformations.

Brick-lined equipment shall be inspected at regular intervals observing any local requirements, and also whenever any leak or product contamination occurs.

The inspection should be restricted to visual observations with consideration of the following:

- General condition of the brick lining.
- Colour of the bricks.
- Level of mortar in joints; excessive chemical attack, e.g. by fluorides, could reduce the thickness of bricks or tiles which may be indicated by protuberance of the joints.
- Regular shape of the brick lining; disbonding of joints could cause irregularities.
- All bricks and tiles in proper position, no loose or displaced parts.
- Cracks; deformation of the equipment due to lack of or improper pre-treatment can cause irregularities.
- Spalling; generally distributed spalling could result from incorrect composition and porosity characteristics of the bricks, or too severe operational conditions caused by frequent temperature or pressure changes. Local spalling could result from direct impact of liquid or vapour jets causing rapid temperature changes, impact and the effect of boiling on the interface level.
- Mortar condition in the joints; erosion, dissolving or washing out, e.g. for silicate-based mortars caused by steam, hot water or chemical attack.
- Lining in and around nozzles and manholes; when design, location, material selection, installation, special treatment and operation are correctly done only minor repairs should be expected.
- When disbonding and spalling of bricks are noticed, this should be further investigated by careful hammer testing.

If visual inspection or hammer testing reveals any such defect, a further thorough examination is necessary. This may require local opening-up of the brick lining, depending on the severity of the damage.

9.2 MAINTENANCE

Maintenance of brick-lined equipment shall be carried out only after the vessel has been emptied, cleaned and dried. Drying is essential, as adhesion between wet mortars and bricks is significantly lower than under normal dry conditions.

To avoid mechanical damage, special protective provisions shall be made for clean-out, scaffolding and brick lining repair activities. Nozzles and manholes shall be opened only when required for access or to provide the appropriate working climate. For the execution of local repairs, the remaining lining shall be properly supported if bricks have to be removed. Shocks and vibrations to the surrounding brick lining shall be avoided.

Even minor defects of brick linings should be consistently repaired to prevent spread of defects to deeper layers of the brick. This includes the replacement of dissolved or washed out cement from joints. Scraping to sound material and subsequent filling with fresh cement is sufficient when the damage is not too deep. When the wastage approaches 75% of the thickness of the top (hot face) brick layer of the lining, the affected area of this layer shall be completely removed and replaced in order to restore the integrity of the lining.

To repair a leak, disbonding, wide cracks, fall-out of bricks or severe spalling, all the affected material shall be removed as far as required to:

- repair or replace part of the locally affected substrate;
- replace the leaking and affected part of the membrane with a correct weld to sound membrane material;
- allow replacement of brick lining rejected by the inspector, and to ensure complete and proper bonding to the remaining brick lining.

All surfaces of substrate, membrane and brick lining shall be thoroughly cleaned and dried before any replacement work commences. The adhesion between mortar and wet or dirty bricks will be significantly lower than with clean and dry bricks.

The original brick configuration shall be maintained on replacement. Welding on brick-lined equipment should be avoided, since most membranes will be permanently damaged and the brick lining will be affected. The thermal expansion of the substrate during welding will loosen the brick lining with the possibility of future leakage.

If welding cannot be avoided, the brick lining and membrane shall be locally removed up to a minimum distance of 500 mm from the weld. After welding, cleaning and drying, proper replacement of membrane and brick lining shall follow as previously described.

Brick-lined equipment standing idle should be protected against frost, especially for those cases where moisture can reach the lining.

10. 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.
Index to standard drawings	DEP 00.00.06.06-Gen.
Design and installation of rubber-lined process equipment, piping and concrete structures	DEP 30.48.60.10-Gen.
Design and installation of chemical-resistant linings for concrete structures	DEP 30.48.60.12-Gen.
Requirements for rubber linings for process equipment and piping	DEP 30.48.60.30-Gen.
Chemical-resistant (ceramic) lining materials	DEP 30.48.60.33-Gen.
Pressure vessels (amendments/supplements to BS 5500)	DEP 31.22.10.32-Gen.
Field inspection methods and repairs of vertical steel storage tanks	DEP 70.51.10.11-Gen.

STANDARD DRAWINGS

NOTE: The latest edition of each drawing can be found in DEP 00.00.06.06-Gen.

Typical details of brick lining constructions	S 10.110
Typical details of brick-lined shell flanges	S 10.111
Typical details of brick-lined flanged nozzles, including manhole	S 10.112
Typical details of rubber-lined flanges	S 10.113

AMERICAN STANDARDS

Standard test method for rubber property - durometer hardness	ASTM D 2240
Standard practice for discontinuity (holiday) testing of nonconductive protective coating on metallic substrates	ASTM D 5162

Issued by:
American Society for Testing and Materials
1916 Race St., Philadelphia
Pa 19103, USA.

GERMAN STANDARDS

Lead used in apparatus engineering; homogeneous lead lining	DIN 28058

Brick-lined vessels and apparatus; design and construction	DIN 28060
Brick-lined vessels and apparatus; examples for test methods for tolerances	DIN 28060 Bbl 1

Issued by:
Beuth Verlag GmbH
Burggrafenstrasse 4-10
D-1000 Berlin 30
Germany.

INTERNATIONAL STANDARDS

Preparation of steel substrates before application of paints and related products - Visual assessment of surface cleanliness - Part 1: Rust grades and preparation grades of uncoated steel substrates after overall removal of previous coatings	ISO 8501-1

Issued by:
International Organization for Standardization
1, Rue de Varambé
CH-1211 Geneva 20
Switzerland.

Copies can be obtained through the national standards organizations.

APPENDIX 1 COMPARISON OF THE CHEMICAL RESISTANCE OF VARIOUS MATERIALS AT 20 °C

	Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Chlorinated Hydrocarbons	Mineral oils	Alcohol's	Ketones	Phenols	Esters	Sulphates	Chlorides	Other salts
Protective membranes											
Hard natural rubber	(+)	-	-	-	+	-	-	(+)	+	+	+
Polyisobutylene sheet	+	-	-	-	+	(+)	-	-	+	+	+
Cold-cured epoxy	+	+	+	+	+	-	-	+	+	+	+
Cements and mortars based on:											
Phenol-furfuraldehyde resin	+	+	+	+	+	+	+	+	+	+	+
Phenol-formaldehyde resin	+	+	+	+	+	+	+	+	+	+	+
Furane resin	+	+	+	+	+	+	+	+	+	+	+
Epoxy resin	+	+	-	+	+	(+)	-	+	+	+	+
Polyester resin	+	+	(+)	+	+	(+)	-	+	+	+	+
Sodium silicate 1)	+	+	+	+	+	+	+	+	(+)	+	(+) 2)
Potassium silicate 1)	+	+	+	+	+	+	+	+	+	(+)	(+) 2)

+ = Resistant

(+) = Limited Resistance

- = Not resistant

NOTES: 1) Sodium silicate and potassium silicate cements have a porosity of 7% to 16% and shall not be used as a membrane.

2) Sodium silicate and potassium silicate cements are not resistant to ammonium fluoride or sodium bicarbonate.

This table should be used only as a guide. Materials should be selected in consultation with a materials specialist.

APPENDIX 1 COMPARISON OF THE CHEMICAL RESISTANCE OF VARIOUS MATERIALS AT 20 °C Continued

	Sea Water	Brackish Water	Potable Water	Ammonia liquid 25%	Hydrochloric acid 35%	Sulphuric acid 98%	Nitric acid 25%	Hydrofluoric acid 50%
Protective membranes								
Hard natural rubber	+	+	+	+	+	+ up to 50%	-	+ 2)
Polyisobutylene sheet	+	+	+	+	+	(+)	+	+
Cold-cured epoxy	+	+	+	+	+	-	+	+ 2)
Cements and mortars based on:								
Phenol-furfuraldehyde resin	+	+	+	+	+	+	-	+ 2)
Phenol-formaldehyde resin	+	+	+	+	+	-	-	+ 2)
Furane resin	+	+	+	+	+	-	-	+ 2)
Epoxy resin	+	+	+	+	+	-	(+)	-
Polyester resin	+	+	+	+	+	-	(+)	(+) 2)
Sodium silicate 1)	-	-	-	-	+	(+)	+	-
Potassium silicate 1)	-	-	-	-	+	+	+	-

+ = Resistant

(+) = Limited Resistance

- = Not resistant

NOTES: 1) Sodium silicate and potassium silicate cements have a porosity of 7% to 16% and shall not be used as a membrane.

2) The filler shall also be present.

This table should be used only as a guide. Materials should be selected in consultation with a materials specialist.

APPENDIX 2 SUMMARY OF THE MAIN REQUIREMENTS FOR MEMBRANES

Requirements	**Criteria - Test Method**	**Membrane material**		
		Rubber [1] (3.2.1) (6.2.5)	**Plastics** (3.2.2, 3.2.3) (6.2.3, 6.2.4)	**Lead** (3.2.4) (6.2.2)
Visual examination	No superficial defects	x	x	x
Adhesion	No lack of adhesion when checked by careful knocking	x	x	x
Porosity	No holidays when tested in accordance with ASTM D 5162	x	x	x [2]
Thickness [3]	Thickness meter	x	x	x
Hardness	Shore durometer	x		
Curing	No softening after 1 minute rubbing with acetone		x [4]	

NOTES:

1. A number of tests are described in detail in DEP 30.48.60.10-Gen.
2. For lead membranes the following dye-checking method shall be used instead of holiday testing:
   - Apply to the surface a 30-40% wt solution of H_2SO_4 for about 2 hours
   - Remove the H_2SO_4 remnants on the surface by washing with water
   - Apply a water wash dyed with Congo Red (benzidine pigment), which will change blue in colour when there is a reaction with remnants of H_2SO_4 emerging from discontinuities.
3. Only required if the substrate is magnetic.
4. Applies only to glass-fibre reinforced epoxy-resin-based membranes.

APPENDIX 3 TYPICAL VALUES FOR MECHANICAL AND PHYSICAL PROPERTIES OF CHEMICAL-RESISTANT LINING MATERIALS*

Property	Units	Acid-resistant bricks and tiles		Porcelain tiles (unglazed)	Carbon bricks		Graphite bricks		Silicate-based mortar	Synthetic-resin-based mortars	
		Glover type	Red acid-resistant		Unimpreg-nated	Impreg-nated	Unimpreg-nated	Impreg-nated		Phenolic and furane	Polyester and epoxy
Apparent specific gravity (density)	kg/m^3	2100-2400	2100-2400	2200-2400	1500-1600	1750-1850	1600-1700	1800-1900	2000-2100	1400-2100	1500-2100
Water absorption	%	1.0	5.0	0.05 max.	12-18	0	14-16	0	1-3	0.3-3.0	0.1-0.5
Apparent porosity, max.	%	5.0	12.0	0.1	18	0	20	0	12	1	1
Acid resistance	%	0.5 max.	1.5 max.	0.5 max.	0.5 max.						
Coefficient of thermal expansion	K^{-1}	$0.5x10^{-5}$	$0.5x10^{-5}$	$0.4x10^{-5}$	$0.5x10^{-5}$	$0.5x10^{-5}$	$0.2x10^{-5}$	$0.4x10^{-5}$	$1.2x10^{-5}$	$2.0x10^{-5}$	$4.0x10^{-5}$
Specific heat	J/(kg.K)	750-840	800-840	800	670-1090	800-1170	670-1090	800-1170			
Thermal conductivity	W/(m.K)	1.1	1.0	1.4	2.3	2.3	116-145	116-145	1.16	1.6	1.1
Compressive strength	N/mm^2	75	110	300	40	75	40	70	50	60	60
Tensile strength	N/mm^2	20	6	35	6	12	5	15	4	8	8
Flexural strength	N/mm^2	25-65	20	60	20	35	15	40		15-29	25-60
Modulus of elasticity	N/mm^2	55 000	55 000	80 000	12 000	20 000	7000	13 000	11 000	8000	8000

* For additional design properties, see Appendix 4.

APPENDIX 4 TYPICAL DESIGN PROPERTIES OF CHEMICAL-RESISTANT LINING MATERIALS [1)]

Item	Thickness mm	Max. temp. °C	Poission's ratio	Mod. of elasticity N/mm^2	Thermal conduc-tivity W/(m.K)	Thermal expansion K^{-1}
Carbon steel vessel wall	10	100 [2)]	0.33		58	1.2×10^{-5}
Hard natural rubber (80° Shore D)	5	80	0.5	3500	0.20	2.0×10^{-5}
Soft natural rubber (65° Shore A)	5	80				
Butyl rubber	5	110				
Polyisobutylene	3	70				
Glass-fibre reinforced epoxy	4	130	0.3	2×10^4	0.29	2.0×10^{-5}
Lead	6	70	0.3		46	
Silicate-based mortar	5 [3)]	900	0.5			
Synthetic-resin-based mortar	5 [3)]	180	0.6			
Acid-resistant brick	65 [4)]		0.5			
Carbon brick (unimpregnated)	40 [4)]		0.6			
Porcelain tile	40 [4)]		0.5			

NOTES:
1. See also Appendix 3.
2. See (5.2).
3. Typical value; actual joint thickness varies between 5 and 10 mm (6.3.2).
4. Typical value, indicative only.

APPENDIX 5 CONFIGURATIONS OF PROCESS EQUIPMENT FOR BRICK LINING

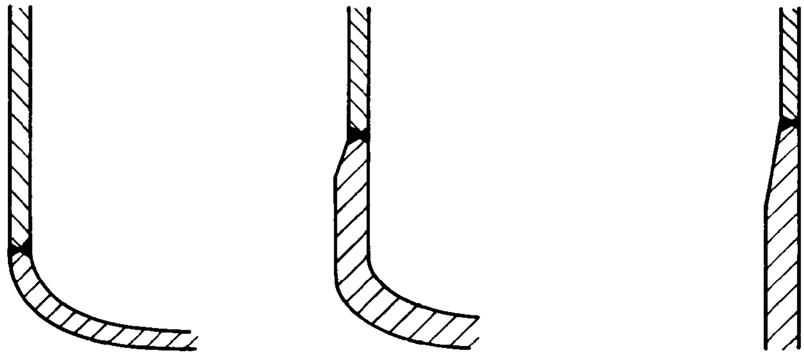


Fig.1 Recommended shapes for cylindrical seams

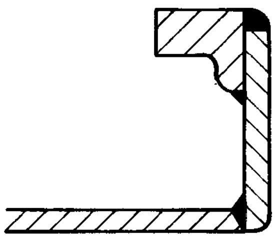


Fig. 2a

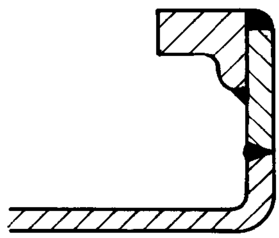


Fig. 2b

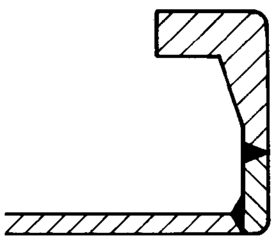


Fig. 2c

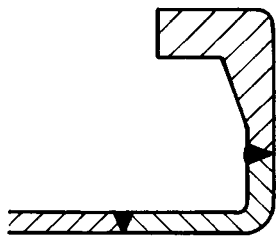


Fig. 2d

Fig. 2 Nozzle constructions

NOTES:
1. All welds shall be finished smoothly.
2. The flange facings should be adapted for receiving a membrane. See also DEP 30.48.60.10-Gen.

APPENDIX 5 CONFIGURATIONS OF PROCESS EQUIPMENT FOR BRICK LINING (continued)

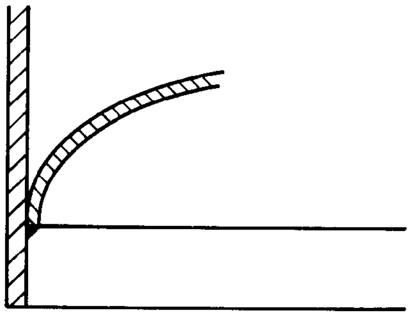


Fig. 3 Form of curved head not to be used

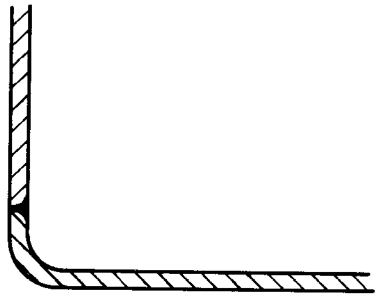


Fig. 4 Recommended joint in a flat bottom

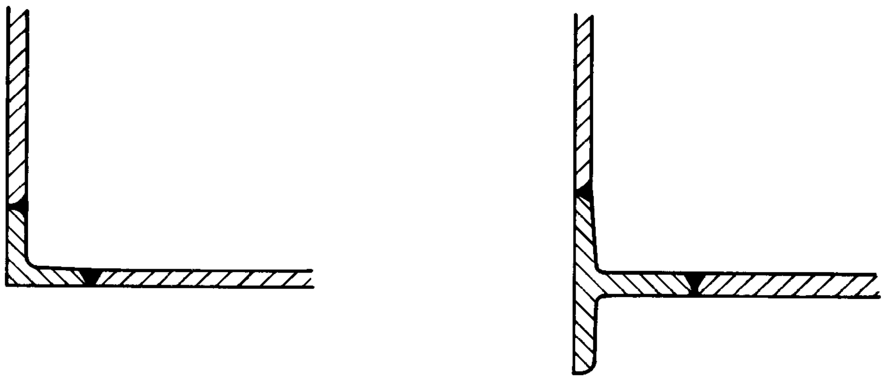


Fig. 5 Recommended construction for flat bottoms in tanks

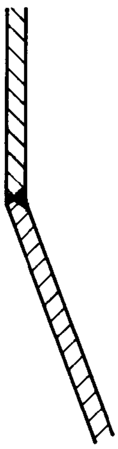
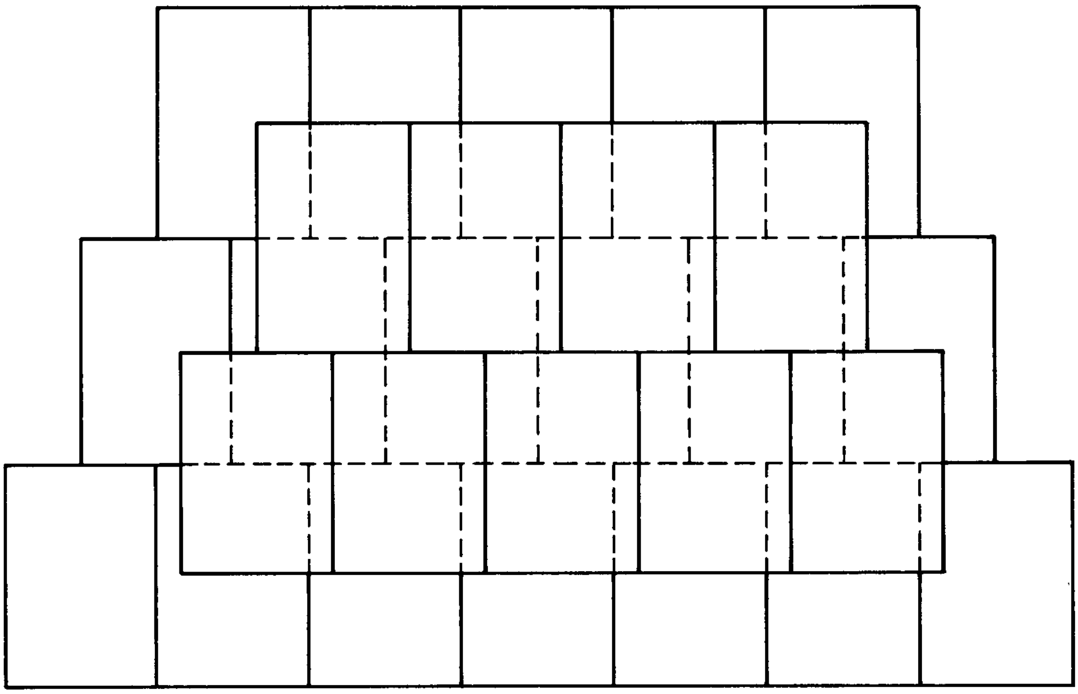


Fig. 6 Recommended joint in a cone-shaped end

APPENDIX 6 OVERLAPPING JOINTS IN A MULTI-LAYER BRICK LINING



APPENDIX 7 INTERNAL STRUCTURES

FIGURE 1 SUPPORT RING OF PRE-SHAPED BRICK

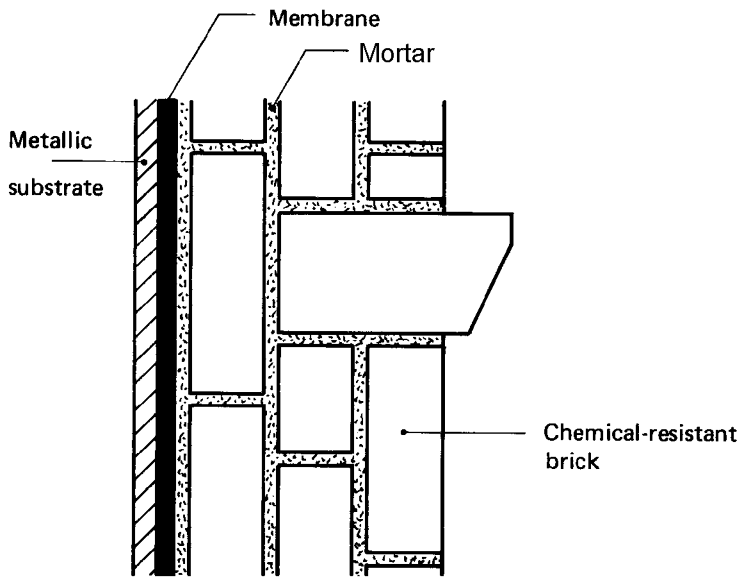
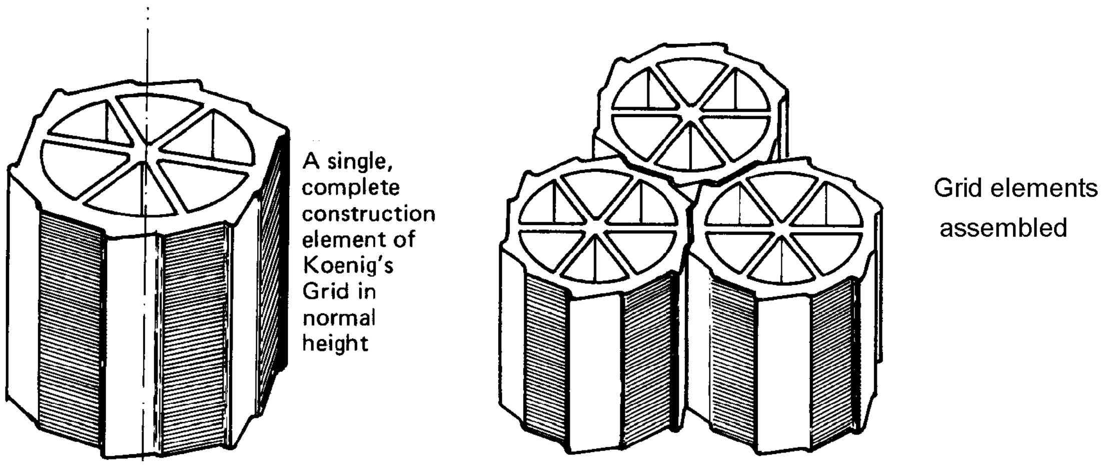
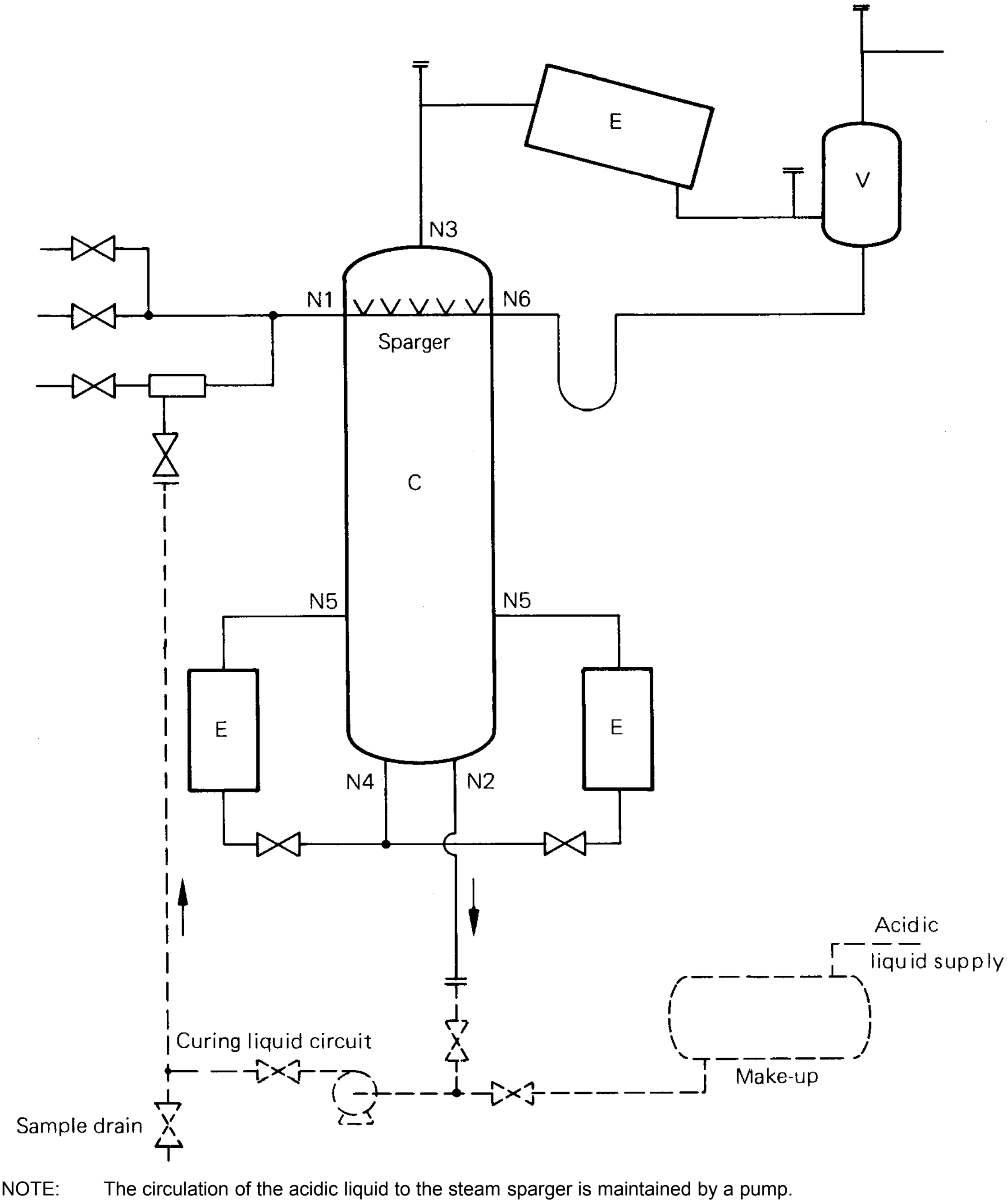


FIGURE 2 SUPPORT GRIDS ASSEMBLED FROM ELEMENTS



APPENDIX 8 CURING OF BRICK LINING WITH ACIDIC LIQUID

Typical example for curing the brick lining installed in a column



NOTE: The circulation of the acidic liquid to the steam sparger is maintained by a pump.

Heat is supplied as steam to the sparger.

The acidic liquid is prepared at ambient temperature in a separate vessel (not shown).

To spray the acidic liquid against the equipment wall a spray pipe is installed in nozzle N1.