TECHNICAL SPECIFICATION

SELECTED MATERIALS FOR FURNACE PARTS FOR HIGH-TEMPERATURE CONVERSION PROCESSES

DEP 31.24.40.31-Gen.

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DESIGN AND ENGINEERING PRACTICE

USED BY

COMPANIES OF THE ROYAL DUTCH/SHELL GROUP

PREFACE

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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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1. INTRODUCTION

1.1 SCOPE

This DEP is a revision of that with the same title and number dated March 1983. It gives guidelines on the selection of materials for furnace parts which under normal operating conditions can have a metal wall temperature above 700 °C. In addition, guidelines are given to assist in the fabrication, inspection and testing of new and used furnace parts and the repair welding of used parts.

This DEP shall be used in conjunction with the code(s) applicable to the equipment under consideration. Welding shall comply with DEP 30.10.60.18-Gen.

The DEP is particularly intended for transfer lines, radiant tubes, fittings and assemblies for:

- steam-naphtha or steam-methane reforming, for the production of synthesis gas or hydrogen.
- naphtha, gas oil or gas cracking, for the production of ethylene or other lower olefins.
- high temperature (process) steam superheating.

For the selection of materials for sections of these furnaces having metal wall temperatures below 700 °C, and for the furnace structure, reference shall be made to DEP 31.24.00.30-Gen.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIPM, 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 and Manufacturers nominated by them (i.e. the distribution code is "F" as defined in DEP 00.00.05.05-Gen.).

This DEP is intended for use in oil refineries, chemical plants and gas plants.

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 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 are made, the number of the section or sub-section referred to is shown in brackets.

All publications referred to in this document are listed in (9).

2. SELECTION OF MATERIALS

2.1 GENERAL

The high temperature furnace parts covered by this DEP shall be made of wrought or cast iron-chromium-nickel alloys.

The materials recommended for the various furnace components are considered to be the best materials currently available for the particular application and are often a compromise in properties/performance.

Wherever possible, alternative materials are also recommended, and these may be considered as preferable where it is either known during design, or discovered during operation, that the furnace components require additional resistance to certain operational characteristics.

Where the furnace designer wishes to use wrought or cast alloys not appearing in the following recommendations they may be used only with the specific approval of the Principal. Before granting approval the Principal may require for review detailed evidence of the materials' high temperature properties, including creep rupture values, along with records of successful applications at other locations.

In the case of cracking furnaces the materials have been selected based on "installed" furnace technology and will therefore be applicable not only to new projects but also to maintenance of existing plant. In this respect a section has also been included on the repair welding of tubes which have been in operation and may have become embrittled. The effects of "new" furnace technology on materials is dealt with in (7.2).

2.2 STEAM-NAPHTHA, STEAM-METHANE REFORMING FURNACES

Furnace Part	Type of Steel	Specification/Remarks
Catalyst tubes, non-fired part up to 800 °C.	Wrought 18Cr-8Ni-Ti.	ASTM A 312-TP 321H (UNS S32109) Note 1)
Catalyst tubes, fired part above 800 °C.	Centrifugally cast 25Cr-20Ni, 25Cr-35Ni-Nb, or 25Cr-35Ni-Nb-Ti.	ASTM A 608 Gr.HK40 Note 2) See also sections 3, 4, 5.
Catalyst tubes, non-fired part, hot end 800 to 900 °C.	Wrought 20Cr-33Ni	ASTM B 407 or B 564 (UNS N 08811 or N 08810)
Thermowells	Wrought 20Cr-33Ni	ASTM B 407 or B 408 (UNS N 08811 or N 08810)
Catalyst gratings	Statically cast 25Cr-20Ni	ASTM A 297-HK Note 3) See also sections 3, 4, 5.
Pigtails	Wrought 20Cr-33Ni	ASTM B 407 (UNS N 08811 or N 08810)
Hot collector	Wrought 20Cr-33Ni	ASTM B 407 (UNS N 08811 or N 08810) ASTM B 366 WPNIC (UNS N08800) See also sections 3, 4, 5.
	Cast 20Cr-33Ni	ASTM A 351-CT15C See also sections 3, 4, 5.
Bolting	Wrought 18Cr-8Ni-Ti	ASTM A 193 - B8T

NOTES:

1) A one hour stabilisation heat treatment at 950 °C shall be applied after solution annealing.

2) Supplementary requirement S4 ("Room-Temperature Tension Test") shall apply and the properties to be met shall be specified by the Principal.

3) Maximum carbon content 0.45%.

Supplementary requirement S7 ("Prior Approval of Major Weld Repairs") shall apply.

Supplementary requirement S9 ("Tension Test") shall apply.

2.3 NAPHTHA, GAS OIL AND GAS CRACKING FURNACES

Furnace Part	Type of Steel	Specification/Remarks
Convection coil tubes and cross-overs (to 800 °C.)	Wrought 18Cr-8Ni-Ti	ASTM A 312-TP 321 H (UNS S32109) Note 1)
Convn.\Radnt. coil tubes (800-900 °C.)	Wrought 20Cr-33Ni	ASTM B 407 (UNS N 08811/10)
Radiant coil tubes (to 1000 °C.)	Centrifugally cast 25Cr-20Ni	ASTM A 608 Grade HK40 Note 2) See also sections 3, 4, 5.
Radiant coil fittings (to 1000 °C.)	Statically cast 25Cr-20Ni	ASTM A 297 Grade HK Note 3) See also sections 3, 4, 5.
Radiant coil tubes (above 1000 °C.)	Centrifugally cast 25Cr-35Ni-Nb 25Cr-35Ni-Nb-Ti/Zr 25Cr-35Ni-W	See sections 3, 4, 5.
Radiant coil fittings (above 1000 °C.)	Static/Centrifugally cast 25Cr-35Ni-Nb	See sections 3, 4, 5.
Thermowells	Wrought 20Cr-33Ni	ASTM B 407 or B 408 (UNS N 08811/10) Note 4)
Transfer linepipe	Wrought 20Cr-33Ni	ASTM B 407 (UNS N 08811/10)
Transfer line flanges/fittings	Wrought 20Cr-33Ni	ASTM B 564 (UNS N 08810)
Transfer line bolting	Wrought 18Cr-8Ni-Ti	ASTM A 193 B8T ASTM A 194 8T

NOTES:

1) A one hour stabilisation heat treatment at 950 °C shall be applied after solution annealing.

2) Supplementary requirement S4 ("Room-Temperature Tension Test") shall apply and the properties to be met shall be specified by the Principal.

3) Maximum carbon content 0.45%.

Supplementary requirement S7 ("Prior Approval of Major Weld Repairs") shall apply.

Supplementary requirement S9 ("Tension Test") shall apply.

4) Due to erosion, external protection by e.g. stellite may be required.

2.4 HIGH TEMPERATURE (PROCESS) STEAM SUPERHEATING FURNACES

Furnace Part	Type of Steel	Specification/Remarks
Radiant coil tubes (to 800 °C.)	Wrought 18Cr-8Ni-Ti	ASTM A 312 TP-321H (UNS S32109) Note 1)
Radiant coil fittings (to 800 °C.)	Wrought 18Cr-8Ni-Ti Cast 18Cr-8Ni-Nb	ASTM A 403 WP 321H Note 1) ASTM A 351 CF8C Note 1) Note 2)
Radiant coil tubes (to 950 °C.)	Wrought 20Cr-33Ni	ASTM B 407 (UNS N 08811)
Radiant coil fittings (to 950 °C.)	Cast 20Cr-33Ni-Nb	ASTM A 351 Grade CT15C
Transfer line piping	Wrought 18Cr-8Ni-Ti	ASTM A 312-TP 321H (UNS S32109) Note 1)
Transfer line flanges/fittings	Wrought 18Cr-8Ni-Ti	ASTM A 403 WP 321H ASTM A 182 F321H (UNS S32109) Note 1)
Bolting	Wrought 18Cr-8Ni-Ti	ASTM A193 - B8T

NOTES: 1) A one hour stabilisation heat treatment at 950 °C shall be applied after solution annealing.

2) ASTM A 351 CF8C shall have a minimum carbon content of 0.04%.

2.5 STATICALLY CAST COIL SUPPORTS

Temperature range	Type of Steel	Specification/Remarks
Up to 1000 °C.	25Cr-12Ni	ASTM A 447 type II Note 1) or ASTM A 297 Grade HH Note 2)
	25Cr-20Ni	ASTM A 297 Grade HK Note 2)
	50Cr-50Ni-Nb	ASTM A 560
Above 1000 °C.	28Cr-48Ni-5W	Proprietary alloys.

NOTES 1) Tensile tested after aging and magnetic permeability tested.

2) Maximum carbon content 0.45%.

Supplementary requirement S7 ("Prior Approval of Major Weld Repairs") shall apply.

Supplementary requirement S9 ("Tension Test") shall apply.

3. MATERIALS SELECTION GUIDELINES.

In formulating the tables in section (2.), wherever possible the materials recommended have been selected from standard specifications. However, in the case of the higher temperature applications, only generic materials types are listed and often with a choice of several options.

For these applications the actual materials choice will be dependent upon a number of factors, e.g. the degree of coking/de-coking policy and the subsequent effect on carburization, the potential for distortion, etc. It is therefore not possible to give only one recommendation for these duties since each furnace design/feedstock type/operational parameters combination will result in differing materials requirements.

In the case of new furnaces it is recommended that the furnace designers make the initial selection of generic material type based upon the design requirements and the known operational characteristics of their furnaces.

Having established the basic generic type of material, a selection from the available proprietary alloys may be made in consultation with the tube Manufacturers based on economic considerations.

Although there are variations in alloy composition from one tube Manufacturer to another within the generic types, it is considered that there is no benefit to be gained from restricting the Manufacturers to minor variations in composition.

The Manufacturers' published mechanical properties shall also be used when determining tube dimensions in accordance with the requirements of API RP 530.

In the case of tube renewals in existing furnaces, the operational history and the primary factors contributing to the renewals may impact upon the selection of the generic type of material selected, i.e. whether to renew in the original material or change if there is potential for tube life improvement.

In this respect some suggestions are made to assist in this decision making process. Notwithstanding these suggestions it is recommended that tube Manufacturers be consulted to establish which of their proprietary alloys they consider to be most suitable.

When evaluating the currently available range of alloys, the best combination of properties is afforded by the microalloyed variation of the 25Cr-35Ni-Nb type. In these alloys, tungsten may sometimes be substituted for niobium and titanium or titanium/zirconium are added up to a maximum of 0.50% weight. This alloy has good resistance to carburization, oxidation and stretching and excellent creep strength.

The enhanced mechanical/creep properties afforded by this alloy shall, however, only be used in calculations when the coil fabrications contain welds of equivalent mechanical properties. The welds therefore should either be autogenous, of equivalent composition or of a composition that generates equivalent properties. In the latter instance, the mechanical/creep properties shall be demonstrated and agreed with the Principal prior to fabrication.

Where an improvement in carburization resistance is desirable, the use of alloys containing (about 5% weight) tungsten should be considered. These alloys also offer reduced stretching characteristics and are therefore useful where excessive creep extension and distortion are of concern; however, they do not offer the same creep strength as the microalloyed materials.

The most significant improvement to carburization/oxidation resistance is obtained by increasing the silicon content. Most tube Manufacturers use silicon in their alloys, especially since it also enhances the castability of the alloy. The benefit of the silicon with respect to carburization/oxidation is offset against reduced high temperature strength and a maximum of 2.0% weight of silicon is recommended.

For applications up to 950 °C the use of the cast version of the 20Cr-33Ni low carbon alloy should be considered, e.g. where reduced age embrittlement and enhanced stress relaxation properties may be of benefit in both new fabrications and repair situations.

There have been developments amongst some Manufacturers to produce bi-metallic tubes which contain an inner layer of material of differing composition. The alloys used for this internal layer are claimed to reduce or eliminate the catalytic effect on coke formation generated from the standard nickel containing alloys.

The bi-metallic tubes currently available are not only extremely expensive but have inherent characteristics which are unattractive, e.g. the differential in coefficients of thermal expansion between the two layers, the difficulties of repair welding tubes in the aged condition and the possibility of failure by high temperature carburisation/oxidation ("metal dusting").

When considering the above and the current Group experience, bi-metallic tubes should not be used for either new or replacement applications.

4. MATERIALS PROPERTIES

4.1 CHEMICAL COMPOSITIONS

Unless otherwise stated the composition of furnace parts shall comply with the referenced standard specifications.

In the case, of proprietary alloys, the alloy composition shall be according to the Manufacturer's published data but shall incorporate the following limits for trace elements:

- lead - 0.005% weight max.
- bismuth - 5 ppm max.
- arsenic, tin, zinc - 0.01% weight max.
- nitrogen - 0.05% weight max.

4.2 MECHANICAL CHARACTERISTICS

The mechanical properties of alloys with referenced specifications shall be in accordance with those specifications; the properties of proprietary alloys shall be in accordance with the Manufacturer's published data and be agreed with the Principal.

For cast parts, in all cases the tensile testing shall be carried out in accordance with ASTM E 8 (or ASTM E 8M) using standard test specimens.

The 20Cr-33Ni-Nb alloy shall also be tested for its susceptibility to age embrittlement. For this purpose a room temperature tensile test shall be carried out after aging for 100 hours at 830 °C. The resulting elongation after ageing shall not be less than 20%, on a gauge length equal to 5 times the diameter.

4.3 CASTINGS

4.3.1 Statically Cast Coil Supports and Fittings

Fittings shall have all ends bevelled to a weld preparation approved by the Principal.

The average grain size for fittings shall be 5 mm maximum, with no cross section having less than 2 grains.

4.3.2 Centrifugally Cast Tubes and Coil Assemblies

The outside surface of the castings shall be cleaned by grit blasting only and shall have a roughness not exceeding 0.8 mm peak to valley.

After fabrication of coils the weld area shall be grit blasted to remove all traces of welding slag/spatter.

The inside surface of cracker and reformer furnace tubes shall be machined by the "pull boring" method to remove the inner layer containing microporosity. As-cast tubes for steam superheaters shall have the thickness of the inner layer containing microporosity agreed between the Manufacturer and the Principal.

Where required, all tube ends shall be bevelled to a weld preparation approved by the Principal.

The following tolerances shall apply to finished tubes and coils:

Inside surface roughness (machined)	Ra = 3.2 µm. max. (BS 1134)
Inside diameter (machined)	-1 to +0 mm
Inside diameter (as-cast)	-2 to +0 mm
Eccentricity	0.05 x max wall thickness
Straightness (per cast section)	1 mm per metre max.
Length	1 mm per metre max.
Weld cap reinforcement	between 1 and 3 mm
Weld root excess penetration	1 mm max.
Weld root penetration (tube to tube for pyrolysis coils)	grind flush

4.4 MICROSTRUCTURAL REQUIREMENTS

Centrifugally cast tubes shall exhibit a grain structure which is not fully columnar but contains 20-25% of equiaxed grains from their inside surface.

5. INSPECTION AND TESTING

5.1 CHEMICAL COMPOSITION

The chemical composition shall be analysed in accordance with the selected ASTM specification or, where the material is not covered by an ASTM specification, one ladle analysis shall be made of each melt (except that arsenic, bismuth, lead, nitrogen, tin and zinc may be analyzed from 10% of melts).

5.2 MECHANICAL TESTING

The mechanical properties shall be tested in accordance with the selected ASTM specification or, where the material is not covered by an ASTM specification, tensile testing (and, for 20Cr 33Ni Nb material, an ageing test) shall be carried out on each of the first ten melts and subsequently on every further tenth melt.

For centrifugally cast tubes with low carbon specifications, the test rings used for microstructural control shall also be subjected to a flattening test in accordance with ASTM A 530.

5.3 SURFACE INSPECTION

Visual and liquid penetrant examination shall be performed in accordance with the following:

	VISUAL		LIQUID PENETRANT (in accordance with ASTM E 165)	
ITEM	Extent	Acceptance criteria	Extent	Acceptance criteria
Statically cast supports	100%	MSS SP-55	100%	ASTM A 903 Level II
Statically cast fittings	100% of outer surface	MSS SP-55	100% of outer surface	ASTM A 903 Level I
			Weld prep plus 10 mm of outer surface	No indications
Centrifigally cast tubes and Coil assemblies	100% of outer surface	Note 1)	Weld prep plus 10 mm of outer surface	No indications
			Inner surface for a distance of at least 2 x diameter	
			Upper side of both weld root pass and final pass	

Note 1) The outside surface of the castings shall be cleaned by grit blasting only and shall have a roughness not exceeding 0.8 mm peak to valley. The surface shall otherwise be uniform and have no mechanical interruptions.

5.4 RADIOGRAPHY

Radiography shall be performed as follows:

ITEM	AREA TO BE EXAMINED	PERCENTAGE EXAMINED	ACCEPTANCE CRITERIA
Statically cast supports	Welds and areas critical for stress concentration Note 4)	100%	ASME VIII, division 2, AM252.1
Statically cast fittings	Areas critical for stress concentration Note 4)	100% of manifolds 10% other Note 1)	ASME VIII, division 2, AM252.1
	Weld preparations	100% Note 2)	
Centrifugally cast tubes.	Weld preparations	100% Note 2)	ASME VIII, division 2, AM252.1
Coil assemblies	Welds	100% Note 3)	ASME VIII, division 1, UW-51 or BS 5500, table 5.7

NOTES:
1) Minimum of one piece of each type per order.
2) Only for preparations not subsequently shop-welded by the Manufacturer (i.e. preparations to be field-welded).
3) Also applicable to weld repairs and rewelding.
4) Areas to be proposed by the Manufacturer for approval of the Principal.

5.5 PRESSURE TESTING

Before hydrostatic testing, all tubes and fittings shall be subjected to an internal air test at a pressure of at least 0.5 bar (ga) for at least one minute while either submerged in clear water (Note 1) or with the entire outer surface coated with soapy water (Note 2). The acceptance criterion is zero leakage.

Each tube, fitting and coil assembly shall be hydrostatically tested for a period of at least thirty minutes at a pressure which generates a stress of 80% of the minimum specified yield strength at the temperature of testing.

Hydrostatic testing shall be done with condensate or demineralized water (up to 2 mg/kg chlorides) **OR** may be done with potable water (up to 200 mg/kg chlorides) **provided** that it is flushed with condensate or demineralized water (up to 2 mg/kg chlorides) immediately after the test (Note 3). All components shall then be thoroughly dried.

NOTES:
1. The above chloride restrictions apply also to the water used in the air test.
2. After the soap test the surface shall be thoroughly rinsed with condensate or demineralized water and then dried.
3. When flushing with condensate or demineralized water it is essential that all surfaces previously wetted during the test are flushed. The quantity and velocity of the flushing water depends on the equipment volume and shall be determined in consultation with the Principal.

6. WELDING OF TUBES AND COIL ASSEMBLIES

6.1 FABRICATION OF NEW COILS

The furnace coils and tube assemblies shall be designed such that welds are avoided at locations where thermal conditions are most severe.

The welding of centrifugally cast tube sections to make up furnace tubes and the welding of furnace fittings to each other and to furnace tubes shall be as follows:

Welds, particularly those which will be located in the radiant section of the furnace, should be made by manual or automatic Gas Tungsten Arc Welding (GTAW) or Electron Beam Welding (EBW). Shielded Metal Arc Welding (SMAW) with coated electrodes shall not be used for root passes.

Welding procedures and welders/weld operators shall be qualified as specified in the purchase order.

Welding consumables shall be selected by the fabricator of the assembly on the basis of experience, and be approved by the Principal. However, high nickel filler metal should be avoided for welds in the radiant section due to the potential for accelerated degradation of the weld by metal dusting. For the microalloyed variation of the 25Cr-35Ni-Nb alloy, the welding consumables shall generate at least the mechanical and creep properties of the component parts.

Prior to assembly the fabricator shall submit, for approval by the Principal, a detailed description of the welding procedures to be used, stating all welding parameters and types of weld consumables to be used, and accompanied by properly documented welding procedure qualification (test) records.

6.2 REPAIR OF OLD COILS

When considering the repair of existing coils there are many factors which must be evaluated in order to produce a satisfactory welding procedure. Any such procedure shall take into consideration the alloy compositions and degree of degradation of each of the component parts and as such may be unique to the particular repair. As a general guide there are certain precautions or parameters which may be considered applicable in all repair situations.

Since residual welding stresses in themselves may generate cracking during repair welding, any additional external stresses should be kept to a minimum. Therefore it is essential to ensure good fit up and support of the components.

The presence of oxide scale on the components induces spatter which can damage the electrode, generating arc instability and hence poor weld quality. All scale should therefore be removed from the area of the weld from both the inside and outside surfaces.

It has been found beneficial to utilise the GTAW process with a shielding gas mixture of 95% argon and 5% hydrogen.

The use of continuous welding has also been shown to be beneficial with pre-heat and interpass temperatures of above 400 °C which minimises the effects of local shrinkage strains and avoids the formation of stress raisers. Nevertheless it may still be necessary to carry out a post weld heat treatment.

Where continuous welding is not feasible it may be necessary to pre-heat to temperatures as high as 700 °C, which is the maximum which will allow control of the welding operation.

A full solution annealing heat treatment may also be considered either before welding in order to reinstate some of the material's ductility or as a post weld heat treatment. Solution annealing is only beneficial when material is slightly carburised.

Continuous, fully automatic orbital GTAW can be executed successfully when all other repair methods fail.

7. DEVELOPMENTS IN FURNACE TECHNOLOGY

7.1 MILLISECOND FURNACES

A current trend in the field of naphtha, gas oil and gas cracking furnaces is to incorporate the millisecond concept into the furnace design. This concept is based upon the operational desire to accurately control the cracking reaction in order to improve efficiency and is best achieved by rapid heating to the cracking temperature, followed by rapid cooling to terminate the reactions.

The result of these requirements has been the design of furnaces with extremely short process residence times (milliseconds).

In order to achieve these conditions it is necessary to reduce the number of coil passes to one or two. Consequently, to achieve the desired heat input, tubes are of smaller bore and may incorporate internal fins.

7.2 MATERIALS SELECTION

In order to achieve the required increase in heat transfer, the development of internally finned tubes has resulted in the use of wrought materials by the furnace designers.

Experience in using these types of tubes is rather limited and will initially introduce additional complicating factors when evaluating tube life or degradation.

As the interest in millisecond furnaces has grown, the Manufacturers of the traditional centrifugally cast tubes have been developing casting techniques to accommodate the requirement for smaller diameter tubes.

It is therefore recommended that when considering the installation of millisecond furnaces both the furnace designers and the tube Manufacturers should be consulted to determine the current state of the art.

Whenever possible it is recommended that the traditional tube technology and materials should be used, for which there is adequate experience in performance/degradation, etc. This will result in the use of small bore centrifugally cast, pull-bored (machined) tubes as detailed in the earlier sections of this DEP.

8. STORAGE

There is a possibility of intercrystalline stress corrosion cracking of all alloys which contain more than 0.15% carbon in environments containing both water and sulphur dioxide. Cracking may occur in areas near welds, particularly in heavy sections, where high stresses are present and precipitation of chromium carbides at grain boundaries has occurred during welding.

Therefore, components or assemblies containing welds in such materials should be sheltered from simultaneous exposure to moisture and sulphur dioxide by, for example, storage inside a warehouse.

9. 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 DEPs and Standard Specifications	DEP 00.00.05.05-Gen.
Welding of metals	DEP 30.10.60.18-Gen.
General type furnaces	DEP 31.24.00.30-Gen.

AMERICAN STANDARDS

Recommended Practice for the Calculation of Heater Tube Thickness in Petroleum Refineries.	API RP 530

Issued by:
American Petroleum Institute
1220 L Street, N.W.
Washington, DC 20005
USA

ASME Boiler and Pressure Vessel Code.	ASME VIII Divisions 1 and 2.

Issued by:
American Society of Mechanical Engineers
345 East 47 th Street
New York, NY 10017
USA

Forged or Rolled Alloy Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High Temperature Service.	ASTM A 182
Alloy Steel and Stainless Steel Bolting Materials for High-Temperature Service	ASTM A 193
Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service	ASTM A 194
Steel Castings,Iron-Chromium and Iron-Chromium-Nickel, Heat Resistant, for General Application	ASTM A 297
Seamless and Welded Austenitic Stainless Steel Pipes.	ASTM A 312
Castings, Austenitic, Austenitic Ferritic (Duplex), for Pressure Containing Parts.	ASTM A 351
Wrought Austenitic Stainless Steel Pipe Fittings.	ASTM A 403
Steel Castings, Chromium-Nickel Iron Alloy (25-12 Class), for High Temperature Service	ASTM A 447
General Requirements for Specialized Carbon and Alloy Steel Pipe	ASTM A 530
Castings, Chromium-Nickel Alloy	ASTM A 560

Centrifugally Cast Iron-Chromium Nickel High Alloy Tubing for Pressure Application at High Temperatures	ASTM A 608
Factory Made Wrought Nickel and Nickel Alloy Welding Fittings	ASTM B 366
Nickel-Iron-Chromium Alloy Seamless Pipe and Tube	ASTM B 407
Nickel-Iron-Chromium Alloy Rod and Bar	ASTM B 408
Nickel Alloy Forgings.	ASTM B 564
Tension Testing of Metallic Materials.	ASTM E 8 (E 8M)
Procedure for Liquid Penetrant Inspection Method	ASTM E 165

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American Society for Testing and Materials
1916 Race Street
Philadelphia, PA. 19193
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Quality Standard for Steel Castings - Visual Method.	MSS SP-55

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Manufacturers Standardization Society
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BRITISH STANDARDS

Method for Assessment of Surface Texture.	BS 1134
Unfired Fusion Welded Pressure Vessels.	BS 5500

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