EUROPEAN
TURBINE
NETWORK

ETN Standard - Gas Turbine Exhaust Systems with or without waste heat recovery equipment for oil & gas, chemical and process industries.

Contents

FOREWORD

ETN was established in January 2005. The association traces its origins back to the EU-funded project under the 5th Framework Programme (FP5), called 'Centres of Excellence for Industrial Gas Turbines' (CE-IGT 2002-2005). As part of this project, a wide-ranging survey, focusing on identifying gaps between the market expectations and the R&D community was conducted among stakeholders in the European GT community. When the CE-IGT project came to an end, many key stakeholders were in favour to join forces to address the technology gaps identified by the survey, resulting in the establishment of the European Turbine Network.

Exhaust System with or without Waste Heat Recovery System for Gas Turbines was identified as such a gap. Accordingly this Standard was prepared by a technical workgroup of ETN members composed of Exhaust System Suppliers, Gas Turbine Suppliers and Oil & Gas operators. Below are listed the organisations comprising the project group.

AAF LIMITED
Aarding Thermal Acoustics BV
ALSTOM Switzerland Ltd.
BIHL – Boustead International Heaters Limited
Camfil Power Systems AB
Dresser-Rand AS
Frazer Nash Consultancy Ltd.
GE Oil & Gas – Nuovo Pignone S.p.A.
Halvorsen Tec
Mjørud AS
Shell Global Solutions International B. V.
Solar Turbines Europe SA
Statoil ASA
TechPart AS
Total SA

A bullet ● at the beginning of a clause indicates that the Purchaser is required to make a decision or provide information. This information should be indicated in the Purchasers enquiry.

1. SCOPE

a) This ETN standard specifies requirements and gives recommendations for the design, materials of construction, modelling, controlling, fabrication, inspection, testing, installation, start-up and operation of GT Exhaust Systems with or without WHRU for use on-shore or off-shore in the petroleum, chemical and process service industries.

b) For the purpose of this Standard, the Exhaust System means all items in the turbine exhaust gas stream between the GT exhaust gas collector outlet flange and the termination to the atmosphere.

c) The following items are not covered by the scope of this Standard:-
   i. Heat Recovery Steam Generator equipment (HRSG)
   ii. Supplementary fired systems see item e) below
   iii. Auxiliary fired systems see item e) below
   iv. Exhaust Gas Collector – see item f) below
   v. Fire Detection and Extinguishing Systems – see item g) below

d) WHRU's exchange gas turbine exhaust heat into single phase heat transfer media, whilst HRSG's involve the evaporation of water into steam (a two phase steam mixture) and superheating of same. This difference adds significant complexity to equipment and system design, control, safeguarding, operation and construction requirements. Certain technical requirements contained in this standard are relevant to HRSG equipment and as such the Purchaser can identify and use those relevant clauses. However in considering HRSG products the Purchaser should address such complexities to ensure that all performance and operational requirements are adequately met

e) GT Exhaust System (including WHRU) equipment covered in this standard is un-fired. The inclusion of supplementary and/or auxiliary firing equipment and systems adds significant complexity to design, control, safeguarding, operation and construction requirements. The Purchaser should address these complexities to ensure that all performance and operational requirements are adequately met

f) The GT exhaust gas collector is typically part of the GT scope of supply and accordingly is not covered in this standard. However certain technical requirements contained within this standard may be relevant to the collector and as such the Purchaser may choose to specify part/s of the standard as technical requirements for the collector supply. Note that both the GT collector and the Exhaust System form the hot gas path therefore considerations shall be given as to how these components are integrated.

g) Where the HTM is flammable, the Purchaser may specify if fire detection and/or extinguishing systems in the Exhaust System shall be supplied. However the requirements for such systems are not covered by this standard and shall be agreed between the Purchaser and the Supplier.

h) The Purchaser shall specify the extent of use of the Appendices A and B and D.

i) The Purchaser shall address the requirements of Appendix C in preparing the RFQ and for project execution.

2. NORMATIVE REFERENCES

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ETN standard. Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments, supplements and revisions thereto.

AMERICAN STANDARDS

ASME BPVC	Boiler and Pressure Vessel Code: Section II, Part D – Materials
	Section III, Division 1, Non Mandatory Appendix N – Article 1300: Flow Induced Vibration of Tubes and Tube Banks
	Section VIII Division 1 – Rules for Construction of Pressure Vessels
	Section VIII, Division 2 – Pressure Vessels
	Section IX – Welding and Brazing
ASME B 16.9	Wrought steel butt-welding short radius elbows and returns
ASME B 31.3	Petroleum Refinery Piping
ASME PTC 4.4	Performance test code for GT heat recovery steam generators
ASME STS-01	Steel Stacks
ASTM C680 – 10	Standard Practice for Estimate of the Heat Gain or Loss and the Surface Temperatures of Insulated Flat, Cylindrical, and Spherical Systems by Use of Computer Programs
CICIND	International Committee of Industrial Chimney
TEMA R	Section VI - Standards of the Tubular Exchanger Manufacturers Association – Flow Induced Vibration

NORWEGIAN “NORSOK STANDARDS”

M-001	Materials selection, August 2004
N-001	Integrity of offshore structures, June 2010
N-003	Action and action effects, September 2007
N-004	Design of steel structures, February 2013

EUROPEAN STANDARDS

DNV-RP-C203	Fatigue Design of Offshore Steel Structures, October 2012
ECFIA	Code of practice of the European Ceramic Fibres Industry Association
EN 287	Qualification test of welders. Fusion welding. Steels
EN 1011	Recommendations for welding of metallic materials General guidance for arc welding
EN 1991-1-4	Eurocode 1: Actions on structures – Part 1-4: General actions – Wind actions
EN 10025	Structural steel standard

EN 10253-2	Butt-welding pipe fittings. Non alloy and ferritic alloy steels with specific inspection requirements
EN 12952	Water-tube boilers and auxiliary installations
EN 13445-3	Unfired pressure vessels – Part 3: Design
EN 13480	Metallic Industrial piping
EN 15614	Specification and qualification of welding procedures for metallic materials

INTERNATIONAL STANDARDS

ISO 3744	*Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering methods for an essentially free field over a reflecting plan*
ISO 9614	Acoustics -- Determination of sound power levels of noise sources using sound intensity
ISO 10494	Gas turbines and gas turbine sets
ISO 10474/EN10204	*Steel and steel products – inspection documents*
ISO 12241	Thermal insulation for building equipment and industrial installations -- Calculation rules
ISO 13704/API 530	*Petroleum and natural gas industries – calculation of heater-tube thickness in petroleum refineries*
ISO 13705/API560	*Petroleum, petrochemical and natural gas industries – Fired heaters for general refinery service*
ISO 13916	*Welding - Guidance on the measurement of preheating temperature, interpass temperature and preheat maintenance temperature*
ISO 14555	Welding - *Arc stud welding of metallic materials*
ISO 14731	*Welding coordination – Task and responsibilities*
ISO 15612	*Specification and qualification of welding procedures for metallic materials – qualification by adoption of a standard welding procedure*
ISO 15613	*Specification and qualification of welding procedures for metallic materials – qualification based on pre-production welding test*
ISO 15614-1	*Specification and qualification of welding procedures for metallic materials*
ISO 19902	*Petroleum and natural gas industries - Fixed steel offshore structures*
IEC61511	*Functional safety - Safety instrumented systems for the process industry sector*
CEN/TR 10347	*Guidance for forming of structural steels in processing*
NFPA 85	Boiler and Combustion Systems Hazards Code

3. ABBREVIATIONS AND DEFINITIONS

3.1 Abbreviations

For the purposes of this ETN standard the following abbreviations apply.

3.1.1. ADLS
Accidental Damage Limit State

3.1.2. CFD
Computational Fluid Dynamics

3.1.3. CHT
Conjugate Heat Transfer

3.1.4. CSCC
Chloride Stress Corrosion Cracking

3.1.5. COTS
Commercial Off The Shelf

3.1.6. DES
Detached Eddy Simulation

3.1.7. DLE
Dry Low Emission

3.1.8. DNS
Direct Numerical Simulation

3.1.9. ETN
European Turbine Network

3.1.10. FAT
Factory Acceptance Test

3.1.11. FEM
Finite Element Method

3.1.12. FLS
Fatigue Limit State

3.1.13. FSI
Fluid Structure Interaction

3.1.14. GT
Gas Turbine

3.1.15. HART
Highway Addressable Remote Transducer

3.1.16. HCF
High Cycle Fatigue

3.1.17. HTM
Heat Transfer Medium

3.1.18. IPF
Instrumented Protective Function (safeguarding by instrumentation)

3.1.19. ITP
Inspection and Test Plan

3.1.20. LES
Large Eddy Simulation

3.1.21. LCF
Low Cycle Fatigue

3.1.22. MLD
Multi Louvre Damper

3.1.23. MPT
Magnetic Particle Test

3.1.24. MSL
Mean Sea Level

3.1.25. NDT
Non-Destructive Test

3.1.26. P&ID
Piping and Instrument Diagram

3.1.27. PMI
Positive Material Identification

3.1.28. PQR
Personnel Qualification Record

3.1.29. PT
Penetrant Test

3.1.30. RANS
Reynolds Averaged Navier-Stokes CFD Modelling (generally referring to modelling steady flow behaviour)

3.1.31. SLS
Serviceability Limit State

3.1.32. SSS
Standard Start-Stop Cycles

3.1.33. SDRL
Supplier Document Requirement List

3.1.34. TEG
Turbine Exhaust Gas

3.1.35. ULS
Ultimate Limit State

3.1.36. URANS

Unsteady Reynolds Averaged Navier-Stokes CFD Modelling:

3.1.37. WHRU
Waste Heat Recovery Unit

3.1.38. WHTC
Wall Heat Transfer Coefficient

3.1.39. WPQ
Welding Procedure Qualification

3.1.40. WPS
Welding Procedure Specification

3.2 Definitions

For the purposes of this ETN standard the following definitions apply.

3.2.1. Analogue Control Signal
A control or digital signal that represents a continuous range of values (e.g. a traditional 4-20mA current loop).

3.2.2. Commissioning
Corresponds to dynamic checks and tests where the GT is running, the Exhaust System is subject to TEG flow and the WHRU is filled with circulating HTMs, progressively loaded with control systems and functioning.

3.2.3. Contractor
The party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Purchaser may undertake all or part of the duties of the Contractor.

3.2.4. Data sheets
Formal documents containing process and/or mechanical data.

3.2.5. Fuel
All fuels specified by the Purchaser for firing in the GT.

3.2.6. Insulation
Insulating materials normally consists of high temperature mineral wool fibre in the form of spun blanket. This form is considered less hazardous to health than ceramic fibre which may be used as an alternative only when local regulation and client specifications permit.

3.2.7. Pre-commissioning
Refers to static checks and tests where the Exhaust System is cold and the WHRU is not filled with HTM and the controls are energized.

3.2.8. Pressure Vessel Code
Design code for the WHRU Tube Bundle pressure parts and/or air reservoir, specified by the Purchaser (e.g. ASME VIII or EN 13445).

3.2.9. Purchaser
The party that enters into contract with the Supplier for the supply of the Exhaust System. The Purchaser will specify the technical requirements. The Purchaser may also instruct a Contractor, an agent or consultant, authorized to act for, and on his behalf. The Purchaser may also be the GT Supplier.

3.2.10. Shall
Shall means mandatory

3.2.11. Should
Should means recommended

3.2.12. Supplier
The party that manufactures or supplies equipment and services to perform the duties specified by the Purchaser.

3.2.13. WHRU Tube Bundle
A hairpin tube bundle arrangement contained within a rectangular casing, or a nested helical coiled tube arrangement contained within a cylindrical casing.

4. PROPOSALS

4.1 Purchaser's Responsibilities

● a) The Purchaser's enquiry shall include data sheets, checklist and other applicable information outlined in this Standard. This information shall include any special requirements or exceptions to this Standard. See Appendix C

● b) The Purchaser is responsible for the correct process specification to enable the Supplier to carry out the Exhaust System design and manufacture

● c) The Purchaser's enquiry shall state clearly the Supplier's scope of supply.

● d) The Purchaser's enquiry shall specify the number of copies of drawings, data sheets, specifications, data reports, operating manuals, installation instructions, spare parts lists and other data to be provided by the Supplier.

4.2 Supplier's Responsibilities

The Supplier's proposal shall include:

a) data sheets for each exhaust system and the associated equipment.

b) an outline drawing showing as a minimum, layout and clearances, arrangement of tube bundles, platforms, ducting, damper systems and stack;

c) definition of the extent of shop assembly, including the number, size and weight of prefabricated parts and the number of field welds;

d) detailed description of any exceptions to the specified requirements including this standard.

e) a completed noise data sheet if specified by the Purchaser;

f) a time schedule for submission of all required drawings, data and documents;

g) a program for scheduling the work after receipt of an order; this shall include a specified period of time for the Purchaser to review and return drawings, procurement of materials, manufacture and the required date of supply;

h) a list of utilities and quantities required;

● i) if specified by the Purchaser, a list of proposed sub-suppliers for major components and items, which may include steel plate, insulation materials, expansion joints, tubes and extended surfaces on tubes, fittings, tube bundle fabrication, dampers, , castings, steel fabrication, ladders and platforms and other auxiliary equipment;

j) Supplier shall identify all parts and components with a shorter estimated life than that specified for the complete system or which will need maintenance and/or removal for service. Expansion joints, damper, actuators and seals are examples of such components.

5. BASIC EXHAUST SYSTEM DESIGN

GT Exhaust Systems may, or may not incorporate a WHRU and damper system which recovers heat from the exhaust of a GT and exchanges this heat into HTM to supplement the thermal requirements of another process. The WHRU enhances the thermal efficiency of the cycle with minimal impact on the operation of the GT itself.

5.1. Exhaust System Configuration

- Each Exhaust System shall normally be connected to its own GT In the event that more than one GT is connected to an Exhaust System then special considerations shall apply which are not covered in detail in this standard.

5.2. Service Life

- Unless otherwise stated by Purchaser, the design, selection of equipment and materials and corrosion protection shall be based on a design lifetime of 20 years with 30 starts/stops from cold to full load per year. The Supplier shall supply the service life and minimum uninterrupted operation interval based on each specific application. The maintenance procedure necessary to achieve these intervals shall also be supplied.

5.3. Supply Responsibility

- Supply responsibility for the Exhaust System may be either with the GT Supplier or contracted directly between the Purchaser and the Exhaust System Supplier.

5.4. GT Characteristic Data

- If the Exhaust System is purchased under the GT Supplier responsibility then the GT Supplier shall provide the required dimensional, thermal and mechanical information to the Exhaust System Supplier as specified in this standard. If the Purchaser shall contract directly with the Exhaust System Supplier then it becomes the Purchaser's responsibility to obtain this data from the GT Supplier and pass it on the Exhaust System Supplier.

5.5. Required Operating Envelope

- The Purchaser shall specify the equipment's required operating envelope in the data sheets including any Dry Run requirements as defined in section 8.3.2.

5.6. Equipment Specification

The Exhaust System design shall be

(i) Proven in practice, robust, reliable, safe and easy to operate.

(ii) Based upon least number of factory-built modules consistent with transport and site erection dimensional and weight restrictions

5.7. WHRU Equipment Specification

5.7.1 The WHRU shall be of the water-tube type (i.e. the HTM inside the tubes)

5.7.2 Materials of construction for the Tube Bundle pressure parts shall be selected from internationally recognized material codes. The Supplier's data sheets shall clearly state the location(s) of each material

5.7.3 The WHRU design shall ensure that the HTM fluid has no phase change throughout the heating process.

5.7.4 The WHRU shall be designed to provide the required performance with no negative tolerance. The design shall consider the selected fouling factor and required degree of over-surface to ensure these guarantee requirements are met

The HTM can typically be the following:

(i) A water/glycol solution
(ii) Hot oil/Thermal oil
(iii) Water
(iv) Hydrocarbons, liquid or gaseous.

NOTE: in the final selection of the HTM, due consideration should be given to operating temperatures and pressures, the degradation limits, surface tension, toxicity, flammability and corrosiveness of the HTM

5.8. Operating Conditions

Each component of the Exhaust System system (e.g. WHRU tube bundle and supports, casings and linings, ductwork, dampers etc.) shall be capable of withstanding the most severe temperature specified plus a margin as defined in section 7.

5.9. Operating Environment

(i) The equipment, including all auxiliaries, shall be suitable for operation under the environmental conditions specified. These conditions shall include whether the installation is indoors (heated or unheated) or outdoors, maximum and minimum temperatures, unusual humidity, and dusty or corrosive conditions, and wind earthquake and sea motions during operation and transport. The unit and its auxiliaries shall be suitable for shipment and installation under the specified conditions.

● (ii) If sub-zero ambient temperatures are specified by Purchaser, then appropriate materials and test procedures shall be applied.

5.10. Equipment Arrangement

● The arrangement of the equipment, including piping and auxiliaries, shall be developed jointly by the Purchaser and the Supplier. The Purchaser shall identify dimensional limitations for the location of the Exhaust System including space required for tube bundle or tube removal as well as any weight limitations that may apply. The arrangement shall be submitted to the Purchaser for review and agreement during the proposal phase.

If there are weight limitations (e.g. max. total equipment weight, maximum lifted weight), the Purchaser shall specify this in the enquiry. If no such limitations exist, at least the total equipment weight with applicable margin (e.g. ± 10%) shall be part of the proposal.

5.11. Electrical Equipment

Motors, electrical components, and electrical installations shall be certified for the area classification specified (class, group, and division or zone).

5.12. Field Assembly and Disassembly

The Supplier shall state in the proposal the offered method for the disassembly required for repair or replacement of Exhaust System parts such as expansion joints, WHRU, dampers or silencers. Whilst tube failures are rare, the design shall include provision for tube bundle pressure part repair or replacement.

5.13. Special Tools and Fixtures

● If special tools and fixtures are required to disassemble, assemble or maintain the unit, they shall be included in the quotation and furnished as part of the initial supply of the equipment. For multi-unit installations, the requirements for quantities of special tools and fixtures shall be mutually agreed upon by the Purchaser and the Supplier.

5.14. Spare Parts

Spare parts and all furnished auxiliaries shall meet all the criteria of this standard.

5.15. Deviations

All proposed deviations of the Supplier equipment from this standard shall be listed by the Supplier with bid.

6. DOCUMENTATION

The Supplier shall provide all drawings, design details, operation and maintenance manuals, and other information necessary for the design assessment, erection, operation and maintenance of the Exhaust System installation. All information shall be clear and not open to misinterpretation and shall apply specifically to the installation supplied.

- The Purchaser shall specify which documentation is required to be provided in a local language.

- The Purchaser shall specify the format and number of copies of documentation required from the Supplier

All calculations and documentation shall be prepared using the agreed unit system for the project.

6.1 Data Sheets

- Data Sheets shall be used for the exchange of information between the Purchaser and the Supplier. The Purchaser shall provide the GT data and corresponding WHRU thermal loads for the required duty envelope. The Supplier shall provide completed data sheets with confirmation that performance requirements are met.

6.2 Supplier Document Requirements

- The Purchaser shall provide a SDRL for the Exhaust System
- The Supplier shall provide the following documents for review unless otherwise specified by the Purchaser.
- The Purchaser shall specify which documents are subject to his approval.

Document	**Remark**
Calculations demonstrating compliance with specification requirements, including any pressure part and structural design codes.	
Data sheets	Detailing process design and performance data at all specified operating cases. Mechanical, materials and construction data Key dimensions and weight
Suppliers Manufacturing Data Report	
FAT Procedure	
Site Performance Acceptance Test Procedure	
General Arrangement Drawings	Showing locations of all materials
Hazardous Area and ingress protection certification for all electrical components.	
• WPS and PQR • WPQ • Weld map • ITP • NDT procedures • NDT personnel qualifications • Procedure for storage and handling of filler metals	

Document	**Remark**
Inspection certificates for all metallic materials of construction.	Material certificates in accordance with EN 10204 / ISO 10474 type 3.1 for all pressure parts and type 2 for materials of exhaust gas ducts/casings. The certificates shall satisfy the applicable code requirements.
Installation, Operating and Maintenance Instructions	
Spare parts list	Commissioning and operational and strategic spare parts lists.
Pre-commissioning and commissioning Instructions	
Pressure and capacity test certificates for any safety valves	
Pressure test certificates for any fabricated pressure parts.	
Quality plan	
Fan and Motor curves and data sheets for all fans.	To include • Sound power levels and sound pressure levels • Test Reports
Sound power levels and sound pressure levels of the equipment.	
P&IDs and controls description including alarm and trip points and cause and effect.	In accordance with appropriate ISO code and shall be complete, comprehensive and consistent
Tube bundle vibration and resonance analysis	
Fluid, Thermal and structural analysis	SEE APPENDIX A and B
Structural dynamic analysis	SEE APPENDIX A and B
Instrumentation Calibration certificates and data sheet.	
3D outside dimensional model	
Packing list and handling instructions	

Table 1 - Documentation to be provided by Supplier for review by the Purchaser

7. EXHAUST SYSTEM ENGINEERING & DESIGN

Exhaust System components are listed below

i. All GT exhaust ducts and transition sections
ii. WHRU/s (Refer also to Section 8)
iii. Damper/s (Refer also to Section 9)
iv. Stack
v. Silencing measures
vi. Expansion joints
vii. Structural steel supports

If WHRU and Damper systems are included in the scope of supply refer also to Sections 8 and 9 for WHRU Process Design considerations and Tube Bundle Design requirements.

7.1 General

● a) As the bases of design for the Exhaust System the Purchaser shall supply the geometry and boundary conditions at battery limits under all specified design and operating conditions and cases, all as detailed in Appendix C,

b) The Purchaser shall take account of the fact that the downstream Exhaust System can affect the flow conditions at the battery limit.

● c) The Purchaser shall specify the maintenance philosophy to be applied in the design of the Exhaust System components

● d) The allowable pressure drop across the exhaust side shall be agreed by the Supplier and the Purchaser, and the Supplier shall submit calculated pressure drop figures for each part of the system with necessary backup information for approval.

e) Flow straightening devices are not recommended.

7.2 TEG Flow Induced Vibrations

For guidance regarding the assessment of flow induced vibration of the Exhaust System casings refer to Appendix A and B.

a) Supplier shall ensure that TEG vortex shedding frequencies do not coincide with the acoustic frequencies which may cause unacceptable vibration of the WHRU tube bundle and casing or other exhaust system components.

7.3 Exhaust System Casing and Ducting

7.3.1 General

● a) Components may be hot casing (externally insulated) or cold casing (internally lined).

Hot casing designs have greater thermal expansion and transient thermal stress and their use is subject to the Purchasers approval.

● b) The Purchaser shall specify in the requisition the extent of CFD or other flow testing of the ducting.

c) Components may be of circular, square or rectangular construction.

d) For hot casing design, circular shape is preferable. If square or rectangular design is used, all corners shall be formed with a radius so that all welding is on the sides of the duct.

e) Any welded attachments inside the TEG path shall be subject to thermal, flow and mechanical analyses and approval by the Purchaser.

f) Transition pieces between duct sections of different cross-sectional areas shall be provided if necessary. Abrupt transitions in cross-section should be avoided.

g) The flow distribution through any change of flow path (shape and direction) shall be taken into consideration for the overall system performance and service life (e.g. performance of WHRU, damper, silencer and GT.

In particular attention shall be given to TEG mal-distribution which may cause:

(i) Preferential heating of the different passes of the coil.
(ii) Flow detachment from the duct wall and adverse effect to TEG pressure drop.
(iii) Adverse effect to silencer performance and lifetime.
(iv) Adverse effect to damper performance and lifetime.

h) Expansion joints may be of fabric or metallic construction and shall be provided in the flue gas ducting as necessary (refer to 7.8).

i) All components (including joints) shall be gas tight to provide zero TEG leakage.

j) Field joints may be seal welded insulated and lagged in the field during assembly. If this is not practical due to maintenance philosophy or accessibility, extra attention shall be given to the design of the field joint.

k) For the component design the gas velocity shall be determined with due consideration of the pressure drop and acoustic requirements.

l) The casing walls shall be constructed of steel plate, 6 mm minimum thickness. The material in combination with corrosion protection shall be proposed by the Supplier if not stated in the requisition.

m) Components shall have a design pressure based on the most severe combination of the wind pressure and 1.5 times the maximum operating TEG pressure in the casing, but not less than 50 mbar. If applicable also explosion loads shall be taken into account.

n) Components design shall take into consideration all other imposed loads such as

(i) Lifting and transportation.
(ii) Installation.
(iii) Motion, e.g. acceleration from seismic events or offshore floatation.
(iv) Snow and ice.

● o) If a combined stack outside the Supplier's scope is used, the Purchaser shall specify the maximum positive and negative design pressures taking into account maximum natural draught and maximum back pressure.

p) Where appropriate (always required for hot casing designs) the design of stiffeners shall take into account thermal expansion and temperature gradients in normal operation and transition cases such as start-up and shut-down.

q) Components shall be designed to prevent vibration, distortion and warping due to temperature, pressure GT pulsations and internal flow. Effective vibration isolation from the GT is particularly essential. Ducting shall be sufficiently rigid to prevent damage from vibration and avoid drumming when exposed to TEG flow over the complete flow range.

r) Component sections shall be suitably stiffened to minimize distortion. Component plate shall be designed to limit the deflections of the span of plate between stiffeners, taking full advantage of multi-span continuity where appropriate, under design conditions.

s) Horizontal (flat) sections shall be avoided i.e. shall be provided with the drainage slope. All horizontal stiffeners shall be designed to prevent water accumulation e.g. weep holes.

t) The exhaust gas system shall be provided with internal drainage connections at low points.

u) All components shall be designed for the intended lifting or installation procedures.

v) For hot casing design, welded lifting lugs shall be removed after initial installation.

● w) The Purchaser shall specify in the requisition if supporting steelwork is in the Supplier scope.

x) The Exhaust System shall be designed to accommodate the thermal expansion with the WHRU and damper and silencer (where installed) normally providing anchor points.

y) Supports shall be provided at each end of horizontal ducting sections and at midpoints as required. One support shall be anchored whilst the others are free to move on sliding pads or small rollers. Sliding supports shall be designed to allow lateral and axial expansion movements of the ducting. If sliding supports are used they shall be high temperature bearing material and heat shielded to protect the bearing material and the structural steel.

z) Component supports shall be designed for all live and static loads, including any uplift due to specified wind and/or other loads. WHRU hydrostatic test condition shall also be considered.

7.3.2 Hot Casing Design and Materials

a) It should be noted that this type of design is susceptible to excessive thermal stresses for the casing, associated stiffeners and structural members even for steady state operation. A FEM analysis shall be carried out to optimize the design to minimize the high thermal stresses during transient conditions and verify that the system will withstand the anticipated number of start/stop cycles during the required lifetime.

b) Hot Casing Design is inherently unsuitable for units in cyclic operation.

NOTE: Good design can minimise these in steady state conditions but higher thermal stress during transient conditions is unavoidable.

c) In parts of the exhaust duct with highly pulsating flow (usually close to the GT), the duct walls (especially non circular) might be exposed to risk for high cycle fatigue due to vibration.

d) Square corners are particularly susceptible to high stresses. Therefore, sharp corner shall be avoided and welds not be placed in areas with high stress.

e) The casing material selected shall be suitable for maximum TEG temperature plus a margin as described in section 7.5.2.1.j.

f) It should be noted that whilst they tend to have lower creep stresses alloy materials have higher thermal conductivity and lower thermal expansion making them less susceptible to thermal stress. The selected material (type and thickness) shall also take into account the corrosive aspect of the flue gas and required surface protection. The material selection will fall into one of the following groups.

(i) Low alloy carbon steel (e.g. 13CrMo4-5, 10CrMo9-10)
NOTE: Low alloy steel materials have good thermal conductivity and low thermal expansion properties, it is therefore a good choice regardless of thermal stress.

i. If low alloy steel is selected strength values at elevated temperature shall be taken from recognized standard and creep shall be evaluated if operation in creep range is expected.

ii. The temperature limits given in the structural code shall not be exceeded.

iii. A surface treatment suitable for service life at high temperature shall be used on all parts to reduce corrosion rate.

iv. A corrosion allowance of 1.5 mm shall be included.

(ii) Stainless steel material, ferritic and austenitic (e.g. AISI316, AISI321)
NOTE: Stainless steel material have good strength values at high temperatures and reduced corrosion rates. Ferritic steels have better thermal conductivity and lower thermal expansion properties than the austenitic steels. Ferritic Steels have lower corrosion resistance than austenitic.

i. Care shall be taken to avoid thermal stress due to temperature gradients during start up and shutdown or change in the operational mode.

ii. For ferritic stainless steels a surface coating suitable for service life at high temperature shall be used on all parts to reduce corrosion rate.

iii. Unless otherwise specified by Purchaser, austenitic steels can be left uncoated if not insulated or exposed to marine atmosphere. If exposed to marine atmosphere stress corrosion maybe a consideration due to chlorides.

(iii) High temperature Ni Cr material (e.g. alloy 800)
NOTE: These materials have improved creep strength at very high temperature as well as very good corrosion properties.

i. Care shall be taken to avoid thermal stress due to lower thermal conductivity and high thermal expansion.

g) Refer to section 7.3.4 on flange-bolts system design.

7.3.3 Cold Casing Design Material

- The material choice shall be guided by the following recommendations:

a) Carbon steel

(i) As the operating metal temperature is relatively low compared to hot casing design the main concern in material selection is to minimize corrosion. The low temperature increases the risk of condensation on the casing surface. This is especially a concern if there are compounds in the fuels which may form acid, such as sulphur.

b) Stainless steel material, (e.g. AISI 316, AISI 321)

(i) Where stainless steel is used for marine environment grade SS316 or SS321 shall be used unless otherwise agreed with the Purchaser.
For marine environments, stress corrosion is not normally considered to be a problem for material below 60°C.

● (ii) Stainless steels are materials which are used in this type of application due to good corrosion resistance or for cases where operation with insulation failure is a specified design condition.

● (iii) The Purchaser shall specify if one of the design modes shall also include “loss of insulation”. This mode could be critical for the design and give the maximum level of stress.
NOTE: Damage to insulation might remain undiscovered over a considerable length of time and when discovered operational needs might not allow for immediate repair.

(iv) For marine environment, the concentration of chloride and other compounds in the exhaust gas may accumulate in the insulation. When specified by Purchaser the stainless steel surfaces, under insulation shall be protected with a suitable surface protection system.

c) Other materials
(i) In marine environment, where stress corrosion is a concern, other materials could also be used based on their corrosion resistant properties.

(ii) However, the risk of change in microstructure of the material due to hot spots or leaking flanges shall be considered.

d) For this type of application, all components joints shall be flanged. Refer to section 7.3.4 on flange-bolts system design.

7.3.4 Flange bolts

a) For flange-bolt systems, rapid temperature rises in the flanges will result in increases in flange thickness due to thermal expansion while the bolt shafts initially remain relatively cold. This can lead, if not addressed properly in the design, to premature (or even immediate) bolt failure, gas leakage and compromised mechanical integrity of the flange connection.

The following factors shall be considered:
(i) flange thickness
(ii) flange material,
(iii) local temperature increase over time,
(iv) ambient conditions,
(v) gasket type
(vi) gasket material,
(vii) bolt material
(viii) bolt manufacturers’ procedures

If not properly considered even the first start up cycle might overstretch a wrongly designed bolt resulting in permanent loss of pretension.

- b) Unless otherwise specified by the Purchaser, for cold casing design all evaluations mentioned under a) shall be part of the flange-bolt design to make the system robust and able to maintain mechanical integrity in case of loss of insulation (accidental load).
  The additional cost associated with this provision may be justified when taking into account the following aspects:
  (i) Depending on design and insulation method, the insulation and lining system in flange areas might be more vulnerable than in a straight duct.
  (ii) When insulation is lost, the mechanical integrity of bolts in the affected area may be compromised during one start/stop cycle.
  (iii) Damage to inside insulation might remain undiscovered over a considerable length of time or when discovered operational needs might not allow for immediate repair.
  (iv) When insulation damage inside the duct might have compromised the bolts mechanical integrity, the exchange of the affected bolts might be costly and time consuming if access is difficult.

c) The Supplier shall design flanges, gasket and bolts as one system and ensure that bolts will operate safely within their elastic operational range even when flanges are fully warmed up to expected steady state temperature while the bolt shaft still is at ambient temperature.

d) The gasket material shall not be a part of flange pretension system.

e) A high temperature anti-seizure compound shall be used as specified by the bolt Manufacturer.

f) The Supplier shall ensure that the bolts under all conditions provide sufficient pretension to ensure gas-tightness and mechanical integrity of the flange connection.

g) The flange bolt system shall be designed to the same operating conditions applicable to the exhaust gas system.

h) Exhaust Systems without internal insulation will usually require the use of tension bolts (extended shaft length).
NOTE: For the installation and tensioning of the bolts a detailed procedure, specific for each given case, shall be developed and followed.

i) Material prone to CSCC is considered unsuitable for Exhaust System bolts in Marine environment.

j) The method of determining the necessary pretension and ensuring that the specified pretension is provided shall be documented where the flange is designed for greater than 250 °C.

k) Acceptable methods of determining the necessary pretension are:-
  (i) FEM Analysis (refer to Appendix B).
  (ii) Stress strain calculations.

l) Acceptable methods of providing the necessary pretension are:-
  (i) Torque wrench

NOTE: Experience has shown that it is very difficult to predict what temperatures flange bolts of Exhaust Systems are exposed to during operation and over the lifetime of a system. Significant contributors to this uncertainty are:
(i) Installation quality of the inside insulation (workmanship) might show variations. That applies especially in flange areas for site built systems.
(ii) Deterioration (local or general) of insulation material
(iii) Potential complete loss of insulation (accidental)

(iv) *Depending on wind, ambient temperature, precipitation, sunshine, orientation the cooling effect might vary hugely*

● m) Due to usually difficult access to the bolts for inspection and replacement, the bolting system selected shall be maintenance free for the service life. The proposed bolt material shall be presented to Purchaser for approval.

n) The nut shall be of a design that eliminates the risk of loosening due to vibration or thermal effects during the entire life span of the system.

7.3.5 Surface Preparation and Treatment

7.3.5.1 Functions

Surface treatment may be required for the following functions:-

a) Protection from corrosion from moisture and condensable sulphur contaminants in the TEG. (Note that cold casing designs have potential for condensation of water onto the casing when ambient conditions are such that the casing is below the dew point of the TEG. The dew point is elevated if SO3 is present in the TEG with resulting condensation of sulphuric acid)
b) Protection from corrosion from constituents in the insulation.
c) Protection from corrosion from weather.
d) Decorative only.

7.3.5.2 Protection from corrosion

When assessing the risk of corrosion, the supplier shall consider the casing material and its susceptibility to attack from:-

a) Moisture together with condensable sulphur contaminants in the TEG.
b) Chlorides in the insulation and possible attack on stainless steel.
c) Marine environment (salt) and possible effect on stainless steel.
d) Weather.

7.3.5.3 Treatment Specifications

● The Supplier shall follow the Purchaser's specification where available and suitable for the application. If not specified by the Purchaser, the Supplier shall indicate in the proposal the type of coatings (internal and external) that he envisages using.

In the absence of a suitable Purchaser specification, the Supplier shall submit a specification for approval. It shall include the following information:-

a) Method statement for Surface Preparation
b) Method statement Surface Treatment
c) Test procedure.
d) Touch-up and Repair procedure.
e) On-site Repair procedure if the surface treatment would be overheated in the event of loss or damage to internal insulation.

7.3.5.4 Requirements for various surface types

7.3.5.4.1 Cold Casing, Internal surfaces

Where the casing material is susceptible to corrosion due to dew point or SO3 it shall be protected by a suitable coating.

7.3.5.4.2 Cold Casing, External surfaces

The treatment shall be suitable for the worst-case calculated operating metal temperature. If the casing is designed to survive loss of internal insulation, the external coating is likely to require repair when the insulation is repaired.

7.3.5.4.3 Hot Casing, Internal surfaces

Surfaces may be left untreated.
A temporary coating may be applied to carbon steel to protect during transportation and storage.

7.3.5.4.4 Hot Casing, External surfaces

The treatment shall be suitable for the maximum specified TEG temperature.
A temporary coating may be applied to carbon steel to protect during transportation and storage.

7.4 Mechanical and Thermal Analysis

a) Supplier shall do a stress analysis using FEM (Appendix B) or other recognised methods in order to verify that all construction elements and details are within predefined acceptance levels.

b) The analysis shall cover both static (e.g. normal operation) and transient cases such as start-up and shut-down.

c) Special attention should be paid to all stress raisers and stress concentration points such as corners, changes in thickness (e.g. flanges), weld undercuts and weld penetrations, equipment mounted to the casing (e.g. lifting lugs, tube hangers, silencer elements), and penetrations.

d) The resonance frequency should also be confirmed by analysis/testing.

e) The possibility for combined creep and thermal fatigue interaction shall be considered in material selection and general design. Refer to Appendices A and B.

7.5 Insulation and Refractory

a) All hot equipment and piping shall be insulated for energy conservation, frost protection (if sub-zero ambient temperatures are specified), prevention of hot surface ignition sources in hazardous zoned areas, to protect adjacent equipment or personal protection purposes.

● b) If energy conservation or prevention of hot surface ignition sources in hazardous zoned areas does not play a role (e.g. stacks) and is not required by the Purchaser, alternative means of equipment or personnel protection (e.g. wire screens) may be applied.

c) The required thickness of insulation shall be determined in accordance with the ASTM C680-10 method (EN ISO 12241).

● d) Unless otherwise specified by the Purchaser, for personnel protection the avoidance of low temperature chloride corrosion on stainless steel in marine environments, the external casing temperature shall not exceed 60°C with the maximum expected air temperature at the operating location and a wind of 1m/s. This calculation excludes the effects of the suns direct radiation. Unless otherwise specified by Purchaser, surface emissivity shall be taken as 0.7. However it should be recognised that this might not be achievable for higher ambient temperatures (e.g. in excess of 30°C).

e) Higher temperatures are permitted at small areas, for example where fasteners, supports or internal attachments are welded to the casing. The hot spot temperature shall not exceed the temperature rating of the hazardous area or the surface coating/paint system.

f) All access doors, hatches and ports for inspection, viewing and maintenance shall be fitted with an insulation system of equal effectiveness to that of the main surfaces. Particular attention shall be given to the design, installation and effectiveness of closing joints such that damage is avoided during opening / closing and hot spots are within acceptable limits.

7.5.1 Exhaust system Casing and Ducting External Insulation (Hot Casing Design)

a) It should be noted that this type of design is more susceptible to excessive thermal stresses for the casing, associated stiffeners and structural members.

b) Care shall be taken to apply the external insulation over all the stiffening and structure which is welded to the casing to minimise thermal gradients from occurring in these members during steady state operation.

c) Care shall be taken to apply external insulation over section flanges to avoid hot spots and to prevent thermal gradients from occurring in these members during steady state operation.

d) External insulation shall be covered with sheeting installed in such a way that the insulation remains dry and free from ingress of water and has sufficient allowance for expansion.

e) Where the risk of hydrocarbons entering into the insulation layer cannot be eliminated (e.g. a leakage scenario close to the exhaust system), the insulation shall be fully covered with a hydrocarbon tight membrane under the sheeting. The membrane material shall be able to withstand the TEG.

7.5.2 Exhaust System Casing and Ducting Internal Insulation (Cold Case Design)

7.5.2.1 General

a) The insulation shall consist of multiple staggered layers.

b) The compression under the lining plates shall not exceed the manufacturers' instructions but shall be adequate to preclude voids.

c) The protective lining plate design shall preclude loss of internal insulation material and may incorporate pillows in support of this requirement.

d) Lining fasteners shall allow free expansion in all directions (floating sheeting).

e) Perforated plates can be used to reduce the noise level. In the case of perforated plates, additional measures to prevent loss of insulating material shall be applied such as stainless steel cloth.

f) Perforated liner plates shall not be used in areas where the TEG flow pattern form a significant risk for flow induced damage or premature failure of lining and/or insulation (for example: several meters downstream the exhaust collector, bends, transition pieces, duct wall area where the flow from turbine compressor bleed flow impinges).

g) A floating internal lining plate system design shall be used for all internal insulation systems. However normal insulation materials may also be considered for high temperature low flue gas velocity applications without lining plates, but with additional protection measures in accordance with the supplier's instructions.

h) The Exhaust System consists of zones with high temperature, high flue gas velocity or a combination of both. The design of the internal lining and insulation system shall be such that long term reliability of the insulation system without a loss of insulation effectiveness is achieved.

i) The design of the internal insulation system shall be suitable for the flue gas velocity and temperature. The fixing method shall allow for thermal expansion without distortion or bulging and shall avoid generating vibration. Materials shall be selected to resist erosion and oxidation.

j) For the casing and ducting sections (tube bundle arrangement excluded), the hot face design temperature for material selection for the liners shall be as follows:
   (i) The maximum TEG temperature plus 30 K, or the highest calculated TEG temperature in the subsequent heat transfer sections plus 30 K.
   (ii) The following table provides guidance for the selection of internal lining materials

Material selection for internal lining	**Maximum temperature during continuous operation**
	°C
11 Cr (e.g. SS 409 / 410)	600
18Cr/8Ni (e.g. 304 / 316)	700
25Cr-20Ni (e.g. SS 310 or Inconel)	750

Table 2 - Material selection internal lining temperature limitation

NOTE: Above 750 °C metal liners are not recommended.

7.5.2.2 Floating Sheeting Insulation Design

a) The insulating material shall have minimum density of 128 kg/m^3 and shall be of a non-carcinogenic type.

b) The insulation shall be secured in position by a grid of fasteners which retain a stainless steel cladding plate which covers and protects the insulation material from the erosion due to the contact with high velocity of the hot exhaust gases.

c) Alternative systems may be proposed by the Supplier for approval by the Purchaser. The selection and application of insulation shall conform to the specified Health and Safety best practices.

d) Care shall be paid to the insulation of field-erected connections and module connections. No cavities under the steel sheeting shall remain unfilled. All connections between pre-insulated panels and site insulation shall be lagged and designed to avoid insulation discontinuities and insulation loss. Particular attention should be placed on installation for designs where the liner is discontinuous at flanged connections between sections. Poor installation resulting in gaps between adjacent liner panels, can cause elevated external flange temperatures and ingress of TEG behind the liner, which can lead to degradation of the insulation and corrosion damage beneath the liner due to acidic flue gas condensate.

e) The insulation plates shall be multi-layered at overlaps and fully lagged in all directions to minimise flue gas circulation beneath the sheeting. The overlap shall be appropriate to the flow direction to prevent ingress of TEG behind the liner which can cause distortion and damage to the lining integrity.

f) Particular attention shall be paid to the design and construction of the ducting lining downstream from the GT Exhaust System interface flange as this is subject to highly unsteady TEG flow condition

g) Where personal access is required lining floors shall be made of minimum 3 mm thick sheeting, whereas walls and roof should be a minimum of 2 mm thick.

h) At the hot face design temperature, the thermal expansion of any plate shall not exceed 20 mm for the extreme diagonal measured between fastener centres.

i) Where studs type fasteners are used the following minimum requirements shall apply, however the Supplier shall remain responsible for the integrity of the design which shall be supported by experience and/or documentation:

  (i) Generally studs shall be welded to the casing.
  (ii) Stud guns shall not be used. Alternative systems can be proposed by the Supplier for approval by the Purchaser.
  (iii) Particular attention shall be paid to stud to casing welds. Welders shall be individually qualified and test welds shall be subject to destructive testing.
  (iv) Stud to casing weld procedures shall be subject to Exhaust System Supplier and Purchaser approval prior to welding and shall include appropriate surface preparation of the weld area.
  (v) Studs shall be M10 minimum for 2mm plate and M12 minimum for 3mm plate.
  (vi) Unless otherwise agreed with Purchaser, studs shall be 316SS material.
  (vii) At each stud, the sequence of assembly shall be - inner nut, washer, plate/s, washer, final nut. The final nut shall be tightened sufficiently to avoid vibration but not so tight as to restrict plate movement; normally ½ turn back from finger tight and secured by a tack weld.
  (viii) Plates shall overlap at least 50 mm and holes shall lie at least 30 mm away from the plate edge. Each hole in the plates shall be at least 3 times stud diameter and allow for the maximum thermal expansion of the plates + 25 % plus fabrication and installation tolerances. Such expansion tolerance may not be required in case a central pin is used which becomes a fixed point for the sheet.
  (ix) The centre hole (fixed point) should be sized for stud diameter only. Alternatively the centre location shall be fixed by appropriate tag welds of washer to plate. Studs shall be at least the same grade as the sheeting as minimum.
  (x) In high exhaust gas velocity areas studs may be welded to scallop bars which are in turn welded to the casing. These provide additional dimensional stiffness to the cladding. The design of the scalloping needs to consider thermally induced stresses and ensures that the weld detail is designed accordingly.
  (xi) Alternative stud fixing systems can be proposed by Supplier for approval by Purchaser. Lining system provided including stud spacing and stud to casing weld can be in accordance with methods demonstrated on units which have been in long term operation if agreed with Purchaser.

j) If surface treatment is required it shall be applied after welding of the studs.

k) Cut-out areas for penetrations such as access/inspection doors, observation ports and instruments, as well as corners and module seal details shall be designed for minimum risk of hot spots.

l) All fastener attachments to casings shall be designed for minimum risk of hot spots.

7.6 Noise Emission and Silencing

a) Where the Purchaser provides a silencer, he shall be responsible to meet the overall noise emission requirements. The Supplier shall provide the silencing effect of the Exhaust System equipment in his scope of supply.

b) If specified by the Purchaser, the Supplier shall provide silencing measures necessary to achieve the specified noise levels.

● c) The allowable noise emission levels for the Exhaust System shall be specified by the Purchaser in the data sheets.

● d) Noise emission data at outlet from GT package shall be specified by the Purchaser in the datasheet

● e) The silencing effect of the Exhaust System shall be considered when designing the silencing measures for the Exhaust System..

● f) Where specified by the Purchaser silencer elements (baffles) shall be replaceable without hot work. This may involve oversized access doors and/or silencer panels in bolt-together sections. Adequately sized access doors shall be installed upstream and downstream of each silencer, to permit the removal/replacement of the silencing panels and/or any other component that needs maintenance.

g) In the event noise measurement is required in order to assess whether the noise levels are met, such measurement shall be performed in accordance with ISO 3744 or where needed ISO9614 for duct wall emissions and ISO10494 for exhaust stack sound power level.

h) If other noise control measures such as acoustic enclosures are required, they shall not in any case obstruct operational or routine maintenance activities.

i) If acoustic enclosures are proposed, prior approval of the Purchaser shall be obtained for their construction, materials and safety requirements.

j) Acoustic insulation of pipes, valves and flanges as necessary to meet the noise level requirements shall be agreed with the Purchaser.

7.7 Stacks

● a) Self-supported stacks greater than 4 outside diameters long shall be designed according to a recognised stack design standard (such as CICIND, ASME STS-01 or other stack design code) agreed with the Purchaser.

● b) The minimum stack length or discharge height about an agreed datum shall be as specified by the Purchaser.

● c) Suitable measures to prevent damage by the ingress of rain or snow shall be provided. Purchaser shall specify the requirement for rain hoods, internal rims complete with adequate drainage facilities or an automatically draining by-pass damper may be considered.

NOTE: Rain hoods have the advantage of protecting against the ingress of rain or snow but the disadvantage of increased pressure drop, disruption of dispersion of exhaust gas and increasing reflected noise to lower elevations.

- d) The Purchaser shall specify the requirement and details of any stack sampling points.

  e) The sampling port or ports shall have blind flange bolted covers. Blind flanges shall be fitted with a threaded cap to allow flue gas spot measurements. The blind flange and bolting material shall be the same as the sample port material. However local regulations may require additional sampling provision.

- f) Un-insulated stacks may be provided with prior agreement with the Purchaser.
  NOTE: In case of an un-insulated *stack, personnel protection shall be provided in areas where personnel access may be required during operation and testing, (i.e., ladders, platforms and base).*

7.8 Expansion Joints

a) The expansion joint(s) shall be designed for all the movements of the exhaust ductwork system and interfacing equipment (axial compression, axial extension, lateral displacements and TEG pulsations).

b) Expansions joints should not be required to accommodate excessive installation tolerances eg. in excess of 15mm.

- c) Expansion joints may be Fabric type, or Steel-Bellows type with inner sleeves, however Fabric type is preferred due to higher flexibility and lower rigidity (both for axial and lateral movements).

d) Fabric expansion joint(s) shall be a flexible multiple layer type and shall be provided with "Bolster Bags" assuring thermal insulation and dampening flow pulsations.. The outer layer shall be fully weather resistant.

e) Steel-bellows type expansion joints applied to hot casing designs shall, if the design requires, be insulated and clad externally, such insulation system shall not inhibit the functionality of the expansion joint and shall, if required, be provided with a rain guard. If the expansion bellows design does not require external insulation and cladding, then personnel protection in the form of a guard and a rain shield shall be provided.

f) The fabric shall be bolted between the casings flange and strips. Flange and strips shall be rounded in all directions and smoothly connect in corners without sharp edges.

g) At the outside, where the fabric is pressed and rubbed against the cover strip, an additional protection layer shall be mounted between fabric and strip.

h) Prior to installation of the fabric, the alignment of the flanges shall be verified to be within the design tolerance for the expansion joint.

i) Each flange of an expansion joint shall be designed to be compatible with the flange of the neighbouring component it is connected to; this with respect to e.g. material choice, thermal expansion, hot- or cold casing. If not otherwise stated the expansion joint shall assure 35 mm axial movement (extension), 50 mm axial movement (compression) and 20 mm lateral movement (in any direction and in combination with axial movement) as a minimum.

j) Expansion joints shall be designed to accommodate all axial and lateral expansions. These shall consider thermal expansion as well as anticipated deflection of the respective equipment under all specified load conditions (e.g. wind and wave induced motions).

- k) Unless otherwise specified the expansion joint at the GT discharge point shall be provided by the GT Supplier and the GT Supplier shall specify the maximum displacements that can be accommodated at this point.

7.9 Steel Structures, Stairs, Ladders and Platforms

● a) Unless otherwise specified by the Purchaser, the support structure and access platforms for on-shore installations shall be provided by the Exhaust System Supplier and for offshore applications the support structure and ladders and platforms shall be supplied by the Purchaser. Supporting steel structures, platforms, stairs, ladders and railings as well as handrail design shall be in accordance with Purchaser's requirements for the actual site/installation.

b) Access facilities shall be provided to all inspection / access openings to facilitate the inspection and maintenance philosophy specified by the Purchaser.

c) Structural design shall take into account the support requirements for all hydrostatic testing (including during manufacture). In addition all other load cases expected during the life cycle of the equipment like transport and erection as well as wind, snow, seismic and explosion loads as applicable shall be covered by the design.

d) Platforms, stairs or ladders shall not be mounted to tube bundle pressure parts or the exhaust duct casing plate (hot stack), nevertheless their mounting to exhaust duct casing shall be allowed for internally insulated ductwork (cold duct).

e) The Exhaust System including the WHRU package shall be supported independently of the GT package.

f) The layout of the support shall not restrict any work to be done on the GT package (inspection, maintenance, partly or complete exchange).

g) It shall be evaluated if the structure for the Exhaust System shall include lifting points or beams with appropriate capacity to be used for work on the turbine package.

h) A material handling strategy shall describe how those components can be removed (including lifting and transport route). The steel structure and concept for access ways and platforms shall accommodate such work.

i) Stairs and platforms shall provide safe and easy access to all valves, gauges, instrument process connections, observation points and access doors, and for all other operational purposes.

j) Ladders may only be used for creating extra means of escape or to reach instrumentation which only requires access for maintenance.

● k) All stairs, platforms and walkways shall be adequately safeguarded with hand railings and toe plates according to the Purchaser's requirements for the actual installation.

● l) Unless otherwise specified by the Purchaser, all main platforms greater than 8m long shall be provided with an emergency means of escape leading down to ground or deck level (i.e. in addition to normal access).

m) No surfaces above 70°C shall be within reach from stairways, ladders, platforms etc. If those cannot be avoided for technical reasons, people shall be protected by appropriate shielding.

● n) Platforms shall have a clear width of 1m and walkways used only to connect platforms shall have a clear width of 0.8m. Stack sample platforms shall have width in accordance with applicable local regulations. All locations required for operation or access to dampers instruments or instrument connections or access doors shall be accessible by permanent ladders or platforms. Permanent platform access shall include:

(i) Exhaust System bottom gas path access platform - one side of Exhaust System, full length of Exhaust System.

(ii) Actuator and hydraulic supply unit for exhaust bypass control.

(iii) Maintenance platforms at all controls, sampling points, control valves, motor operated valves, drain and vent points and all valves not accessible by other platforms. Any control valves located at grade do not require a platform.

o) Ladders access shall include, but are not necessarily limited to, access to the following locations:

- (i) Instrumentation not accessible via the above platforms.

  (ii) Stack emission test platform to provide access to the flue gas emission (nozzles) and flue gas emission monitoring equipment (if installed).

7.10 Preservation, Handling, Packing and Storage

7.10.1 Handling and Storage of materials

a) Materials shall be handled and stored in conditions that are in accordance with product Supplier's recommendations.

b) Materials and components shall be new and unused. Products that have been handled or stored in a way or for a length of time that could have led to significant deterioration shall be checked before use to ensure that they still comply with the relevant product standard.

c) Structural steel components shall be packed, handled and transported in a safe manner, so that permanent deformation does not occur and surface damage is minimized.

7.10.2 Preservation and Packing

- In the absence of Purchaser specifications Supplier shall specify and apply methodologies and measures for preservation and packing to meet the project requirements. The measures shall include procedures to protect the equipment during pre-shipment, transportation and storage prior to construction, during construction, before start-up and for prolonged shut-down: Minimum measures pre-dispatch shall include:

a) Thorough cleaning and drying.

b) Closure of all flange openings for atmospheric protection and to prevent foreign matter from entering during transport or installation.

c) Protection of all exposed carbon steel surfaces from atmospheric corrosion.

d) The interior of the carbon steel tube bundles should be purged and maintained with nitrogen at a positive pressure of 0.35 barg or equivalent system.

7.11 Inspection and Testing

a) The Supplier shall submit an Inspection and Test Plan to the Purchaser for approval.

b) The ITP shall detail all inspection and testing procedures as described in the Supplier's quality plan and as required by the design code.

7.11.1 General Inspection

a) The Supplier's manufacturing workshop(s) for the pressure part modules should be subject to approval by the Purchaser.

b) The Supplier shall at start-up of the project submit his quality plan and ITP for approval by the Purchaser. The ITP shall specify all documentation and equipment inspection requirements and associated testing procedures and all activities that are to be performed to ensure appropriate quality of the equipment and compliance with all applicable standards, codes and specifications.

c) These documents shall be submitted to the Purchaser for comments/approval.

● d) The Purchaser shall advise which of the inspection activities he wishes to witness and form of participation (e.g. direct witness, review of documentation/photographs) and the Supplier shall give notice of at least two weeks (or other period that shall be agreed) of such inspections.

e) Supplier shall provide appropriately qualified and dedicated inspection personnel.

f) The Supplier shall perform inspection and tests in the shop and in the field where the Supplier is responsible for site construction as described in the Supplier's ITP and as required by the design code. Supplier is responsible for appropriate involvement of third parties and Notified Bodies as required to ensure quality and compliance as well as related documentation.

7.11.2 Specific inspection requirements

7.11.2.1 Quality Control

a) Welding inspection requirements during fabrication:
   (i) 100% of pressure parts and non pressure parts welds of the complete Exhaust System shall be visually inspected
   (ii) Unless otherwise specified by the Purchaser 100% of the butt welds in tube bundle/s and headers shall be subject to radiographic testing
   (iii) Unless otherwise specified by the Purchaser, All welds in non-pressure parts shall be subject to 100% visual inspection.
   (iv) Design of the tube to header welds shall permit visual inspection of the root of the weld. Where headers are too small to permit access for inspection, separate stubs shall be used and roots examined with dental mirror.

b) Where dye penetrant is used, it shall be free of residual chlorides.

7.11.2.2 Insulation

a) The Suppliers Inspector shall inspect the installation of the entire insulation system during and after the installation process but before liner plates and/or cladding materials are fixed in place.

b) This activity shall be part of the Inspection and test plan and the Purchaser shall be invited to attend.

c) The Suppliers inspector shall verify that the insulation system complies with the Suppliers specification and / or this Standard, e.g.
   (i) (New item) the insulating material is of the correct type and specification – K value, density and thickness
   (ii) the entire area that should be insulated is fully covered, without gaps.
   (iii) the insulation material is installed in accordance with the design, with the correct compression and secure against movement.

d) A report with photographs of the installed insulation shall be issued.

7.11.2.3 Liners (for inside insulation)

a) Depending on how the plates are fixed, special attention is to be given to mechanical strength and correct installation of the fixation, possibility for free float of the liners during thermal expansion as well as sufficient and correct overlap.

   NOTE: It is strongly recommended that a Supplier-dedicated inspector supervises the installation of the insulation and the liner system.

b) Supplier shall ensure that fixings (including pins) or other parts which secure liner plates or cladding are installed correctly, are the correct length (to compress the insulation layer), have appropriate mechanical strength and are installed in the correct locations.

7.11.2.4 Verification of Effectiveness of Insulation

a) Once the system has at least collected 100 operating hours a thermographic survey covering the complete outside of the Exhaust System is recommended to be performed while the gas turbine is running at normal load.

b) The purpose of this examination is to:
   (i) Verify that the insulation is installed correctly and that the surface temperature and any local hot spots do not exceed the accepted limitations (be aware that measured temperature is effectively influenced by environment condition)
   (ii) Establish by visual and thermographic inspection that there are no detectable leaks.
   (iii) Confirm that the contractual agreed maximum surface temperature is not exceeded in the agreed upon area and location
   (iv) Provide a record against which future thermographic surveys may be compared in order to evaluate possible changes in insulation performance (degradation, damage etc.)

8. WHRU Engineering & Design

8.1 WHRU Process Design

● a) The Purchaser shall specify the required process guarantees, which may include thermal performances, tube-side pressure loss, draught loss, noise emissions, surface temperature.

● b) A 10% over-surface margin shall be included over and above that calculated for the appropriate design case including in the fouled condition. The Purchaser shall specify any variance to this margin.

c) The Supplier shall take account of the flue gas velocity profile resultant from the chosen or proposed Exhaust System configuration.

d) To prevent degradation of the HTM (e.g. by local boiling or cracking), the maximum HTM temperature in the tube bundle shall be limited such that the operating pressure always exceeds the HTM vapour pressure. To demonstrate compliance, the Data sheets shall state:
   (i) Maximum HTM bulk temperature.
   (ii) Maximum HTM film temperature
   (iii) HTM vapour pressure at Maximum HTM temperature
   (iv) Minimum system operating pressure

e) The Supplier shall specify the minimum HTM flow rate that it is required to the WHRU - when operating in by-pass mode - to prevent boiling and degradation of the HTM (e.g. cracking due to excessive film temperature caused by TEG leakages through the damper/louvres).

● f) The allowable pressure drop across the HTM side should be agreed by the Supplier and the Purchaser, and the Supplier shall submit calculated pressure drop figures for each part of the system with necessary backup information for approval.

g) Unless otherwise agreed with Purchaser the HTM inlet temperature at the coldest section of any tube shall be at least 10 K higher than the dew point of the TEG for all operating cases. In event that sulphur or other similar contaminants are not present then the dew point shall be the water dew point.

h) When the HTM is flammable then a tube leak has the potential to cause a fire or in extreme cases an explosion. The extent of monitoring and mitigation measures shall be agreed between the Purchaser and the Supplier.
Means of detection can include the following:

   (i) Temperature
   (ii) Combustible materials monitoring
   (iii) Opacity monitoring
   (iv) Provision for visual observation

Possible mitigation actions include the following:

   (i) Water fog
   (ii) Carbon dioxide snuffing
   (iii) GT shutdown
   (iv) Isolation of the HTM

8.2 WHRU Tube Bundle Mechanical Design

8.2.1 General

a) Tube bundles shall be of all-welded construction.

b) The design of the tube bundles and casing shall be such that the possibility of TEG bypassing the tube bundle is minimized. The configuration shall also ensure effective clearance of pockets of air or flammable gas during purging, i.e.no stagnant zones.

● c) Restriction orifices or reduced header drilling for equalizing flow distribution across tubes with parallel flow shall not be used in any part of the WHRU unless approved by the Purchaser.

d) The tube bundle arrangement shall permit free thermal expansion of all tubes, headers, tube supports and casings and linings. The tube bundle arrangement shall take due account of any potential differential heating between individual tube passes.

e) The tube bundle can either be a rectangular serpentine design or a circular helical coil design.

● f) Tube bundles may be in-line or staggered pitch. Some staggered tube arrangements may not be readily drainable. In-line tubes pitch arrangements may make finding the source of tube leaks easier and Purchaser shall specify if in-line tubes pitch is mandatory.

g) Tube-to-header welds shall not be exposed to high heat flux. If such connections occur within the casing they shall be located outside the main flue gas flow and shielded by baffle plates or tube sheets.

h) The number of casing penetrations shall be minimized.

● i) The tube bundle assembly including headers carrying the HTM fluid shall be self-draining unless otherwise agreed by the Purchaser. The assembly shall be equipped with sufficient drains and vents to permit drainage and filling in the installed position. Unless otherwise specified by the Purchaser drains and vents shall be sized in accordance with Section 10.1.6.

Note: It is common practice in piping systems to provide a drainage slope of at least 1:100, but this is impractical in a WHRU tube bundle where tubes are normally horizontal or near-horizontal, consequently complete inherent self-draining is unlikely without assistance. Furthermore not all tube bundle configurations are inherently self-drainable (e.g. staggered pitch with horizontal flue gas flow).

The tube bundle may be drained for any of the following reasons:
(i) Off-load frost protection when HTM is water only.
(ii) For in-situ tube bundle inspection and / or maintenance.
(iii) For tube bundle assembly removal.
(iv) For dry running.

NOTE: Before being allowed to run dry, a tube bundle that has contained thermal oil or water-glycol, shall be drained as far as is practical and then internally force-flushed in accordance with an approved procedure to remove any hydrocarbon residues which could coke or combust under such operating condition. When a tube bundle is intended for thermal oil or water-glycol, but none has been introduced, it may be run dry provided the design is otherwise suitable for dry-running. (This allows the turbine and dampers to be commissioned in advance of the HTM system.)

j) For WHRUs configured from multiple bundles, e.g. where weight and/or installation or maintenance restraints apply, interconnections shall be by intermediate headers and external cross over pipes.

k) In properly designed WHRU tube failures are a rare occurrence. Nevertheless, tube repair procedures shall be considered in the design.

8.2.2 Fouling Factors

● The Purchaser shall specify internal and external fouling factors. However, the Purchaser may request the Supplier to determine these factors, in which case such determination shall be based upon HTM and TEG data.

The table below provides suggested process side fouling factors considering different types of fuel gas and liquid fuel feeding the GT should be used as guidelines for the Purchaser. The table has been grouped into three categories: clean gas, average gas and dirty gas.

Type of exhaust gas	**Units**	**Fouling Factor**
Clean gas (cleaning devices (1) not required)		
GT firing natural gas	m²°C/W	0.000176
Average gas (provisions for future installation of cleaning devices)		
Other gas	m²°C/W	0.00035
Dirty gas (cleaning device required)		
GT firing liquid fuel (diesel)	m²°C/W	0.000528

(1) Cleaning devices include steam and air blowing, water washing, chemical and mechanical processes.

Table 3 - Fouling factor for exhaust gas

The fouling factors relevant to the HTM side (such as water, water-glycol, hot oil, etc.) can be found in specialist literature or directly available from the fluid suppliers.
Even if the exhaust gas is clean, the WHRU Supplier shall indicate in the operating and maintenance manual all the information relevant to the cleaning operation.

8.2.3 Pressure Part Design

● a) The Purchaser may specify one of the following paired options for tube bundle pressure part design

Unfired	
TUBES	**HEADER**
ASME VIII – DIV.1	ASME VIII – DIV.1
ISO13704/API530	ASME B31.3
EN 13445	EN 13445

● b) Unless specified otherwise by the Purchaser, external or interconnecting piping shall be designed and fabricated according to *EN 13480 or* ASME B31.3. However the design, construction, inspection, etc. shall be in compliance with the specified code.

c) The Supplier's own stamping in accordance with e.g. ASME VIII shall be deemed adequate.

d) The Supplier shall obtain all code stamps and certificates required by local regulations.

e) Where the equipment is supplied into the European Economic Area or where specified by the Purchaser, the equipment shall be supplied in accordance with the European Pressure Equipment Regulations and other relevant EU directives and be accordingly CE marked by the Supplier in co-ordination with the Supplier's selected Notified Body.

f) If the WHRU is to be subjected to a high number of start-stop cycles or if there is risk of tube vibration impacting the cycle fatigue of the equipment, then appropriate fatigue analysis shall be performed (Appendix B).

g) In the event that tube bundles are subject to cycling flow conditions such as regeneration gas applications, effects of cyclic thermal stresses shall be considered in the design and calculations shall be provided to demonstrate that thermal stresses shall be less than 85% of that required to produce a crack based on the lifetime number of cycles (Appendix B).

8.2.4 Corrosion Allowances

● a) When the HTM is not corrosive; an internal corrosion allowance may be unnecessary, however the Purchaser may specify otherwise.

b) There may be some risk of external corrosion, particularly where tube surfaces operate close to acid dew points.

c) For corrosive conditions, the allowance shall be according to ISO 13705/ API 560.

● d) Application of corrosion allowances can force the selection of increased tube wall thickness. Rather than unnecessarily increase the tube bundle weight and cost, the Purchaser may prefer to work with the Supplier to identify available margin within the standard wall thickness and consider if that is adequate.

NOTE: The thickness of the tube selected for mechanical/manipulation purposes usually significantly exceeds that necessary for pressure containment, where significant allowance may be available within the standard wall thickness

8.3 WHRU Tube Bundle Design

8.3.1 Tube and Bend Materials

a) Both 'pipes' and 'tubes' are permitted and hereafter referred as tubes.

b) The tubes and bends shall be seamless. Header tubes may be welded where seamless tubes are not economically available. In this case weld seams shall not overlap with nozzle welds and appropriate NDE and weld strength reduction factors according to the selected code shall be applied.

● c) A straight tube or pipe in a tube bundle shall not be composed of two butt welded parts, where the tube length is less than mill production (typically less than 12m) unless approved by the Purchaser.

d) Any return bends shall be butt weld return bends and comply with ASME B16.9 or EN 10253-2. Return bends shall match the inside diameter of the connected tubes.

e) Bending of tubes and pipes shall be in accordance with the relevant code. The Supplier shall present a bending procedure.

● f) The bending procedure shall be approved by Purchaser and shall be accompanied with an inspection report demonstrating that wall thinning is within acceptable limits and that surface cracking is absent.

g) Where tubes are bent, the resulting thickness of the tube in corroded condition at the thinnest part shall not be less than the design value calculated in accordance with section 8.2.3.

8.3.2 Tube Bundle Design Conditions

Typical exhaust gas temperatures of gas turbines are in a range where mechanical properties of some commonly used tube bundle materials are highly temperature dependent.

While too low a design temperature for the tube bundle pressure parts might lead to safety risk and premature failure, a too conservative design temperature might trigger the use of very costly material which in addition might introduce other technical disadvantages

For determination of the correct tube bundle design temperature the following approach is recommended.

a) Determine the maximum TEG temperature:

The maximum TEG temperature shall be determined in close cooperation with the Purchaser and its determination is likely to include consideration of the following factors:

(i) Type of engine
(ii) Combustion system

Note: On some gas turbines with DLE combustion system, the TEG temperature in part load can be significantly higher than at full load

(iii) Ambient temperature range
(iv) Fuel(s) used
(v) Range of operational loads
(vi) Exhaust Gas conditions applying at the end of the specified operating period, i.e. immediately prior to maintenance

Note: An engine due for overhaul will have a higher TEG temperature than a new or newly overhauled one

(vii) Turbine trip temperature
(viii) Any other factors which may affect the engines operation

b) Evaluate the operational conditions:
Operational circumstances where the tube bundle is exposed to the TEG temperature while there is no HTM inside the tubes is commonly called “dry run”.

However, for the purpose this evaluation it shall also mean no flow of HTM.

Under such condition no cooling of the tube material is present and the tube material temperature will reach the TEG temperature if the tube bundle is not completely isolated from the TEG.

In many cases, it will be impossible to completely rule out occasional dry run. However, a realistic determination of expected operational circumstances and expected extent of dry run is an important input for design and material choice of the tube bundle.

It shall be noted that based on design and geometry, e.g. the headers (even if not directly exposed to TEG flow) might under dry run condition reach a temperature close to the TEG temperature.

The design temperature of parts and components exposed to TEG shall not be lower than the maximum calculated tube metal temperature in the fouled condition plus a margin of 30K.

Note: Even with no dry run anticipated, the margin is required as the following aspects will usually cause local tube wall temperatures to be higher than calculated:

(i) HTM flow imbalances
(ii) TEG flow imbalances
(iii) Peak local heat flux

Dry run usually has to be taken into consideration for all installations where in case of failure in the HTM system (e.g. circulation) a GT-trip is unacceptable and complete isolation of the bundle cannot be achieved. In such case, one or a combination of the following scenarios might apply:

(i) Short term no flow pressurized operation

The dry run may occur during start-up or the time it takes between failure in the HTM system until the complete TEG flow are routed through the bypass and depressurizing the HTM system.

(ii) Long term dry run

Systems that do not have a TEG bypass but where depressurization of the bundle in case of non-operating HTM system is guaranteed.

Systems which do have a TEG bypass but where the damper towards the coil does not guarantee a positive insulation of the coil.

Note: heat leakage can be e.g. TEG leaking through seals or radiation through the damper itself.

Systems which do have a bypass and might even have a damper which guarantees a positive isolation of the tube bundle towards TEG flow from upstream (e.g. by means of double damper and sealing air), but where the layout of WHRU and bypass can lead to a heating of the tube bundle from its downstream side either by radiation or backflow. The scenario is not uncommon in certain compact WHRU designs.

(iii) Long term pressurized dry run

Systems where heat exposure of the bundle cannot be ruled out and a depressurization of the tube bundle is not possible for e.g. operational reasons. This condition should be avoided as it has significant implications to mechanical design.

The possibility of tube service life limitation due to creep shall be evaluated as part of the design work.

Creep might be a life limiting factor even in normal operation (without dry run) depending on a number of factors including TEG temperature, HTM temperature, selected tube material and design code.

With dry run anticipated (especially pressurized) the likelihood of creep limiting the design life increases.

If the spacing between tube supports exceeds 35 bare tubes outside diameters (ISO 13705/ API 560) creep due to sagging shall be considered.

If creep limits the service life of the pressure parts below the overall service life of the system specified by the Purchaser, the Supplier shall notify the Purchaser and obtain acceptance or propose alternatives if the Purchaser requests so.

The design pressure of the pressure retaining parts shall not be lower than the safety valve lift pressure.

8.3.3 TEG Flow Induced Vibrations

For guidance regarding the assessment of flow induced vibration of the casing refer to Appendices A and B.

b) The Supplier shall include in the design all measures necessary to ensure that no part of the WHRU tube bundle shall be subject to vibrations that may reduce the life of the systems below the design life, or create equipment noise exceeding the specified emissions.

c) Frequencies of gas vortex shedding from the tubes shall not coincide with the natural frequencies of the tubes.

The table below resumes acceptance criteria that shall be verified to ensure that there aren't any flow induced vibrations:

Frequency	Operating conditions	Tolerance from gas vortex shedding frequency
Natural frequency of the tubes 1rst mode	All conditions	+/- 20%
Natural frequency of the tubes 2nd mode	All conditions	+/- 20%

Velocity	Operating conditions	Tolerance from critical velocity: fluid elastic instability
Tube bundle crossflow velocity	All conditions	-20%

- If dry run is specified by Purchaser, the vibration behaviour (natural frequency) of the empty tubes shall be evaluated as well.

d) The Supplier shall provide a vibration analysis report showing Strouhal numbers, and the gas vortex shedding frequencies for each tube bundle, as well as the lower natural frequencies of the tubes, and the acoustic frequencies of the WHRU casing taking into account the presence of tubes.

The table below resumes acceptance criteria that shall be verified to ensure that there aren't any flow induced vibrations;

Vibration	Operating conditions	limitation
Maximum vibration amplitude	Gas vortex shedding resonance condition	0.02*ODtube

e) In case the Supplier cannot provide a rigorous vibration analysis considering the tube as a multispan beam and using dedicated proprietary and/or internationally recognized software tools, he can follow the simplified calculation procedure reported in Sect. 6 of TEMA, or similar procedures, which evaluate the potential for vibration in each individual unsupported span of the tube. This simplified calculation procedure considers the tube as a continuous elastic beam on multiple supports with fixed end conditions and simply supported at the intermediate points (tube support locations). The individual spans are each treated as a separate beam with its own end conditions (fixed-pinned, pinned-pinned, etc.) and subjected to local exhaust gas flow velocity distribution. Natural frequencies of the individual spans are calculated and the lowest frequency of the spans is taken as the representative figure of the whole tube. These calculations shall be performed for each type of tube. When the gas flow is non-uniform over the entire tube bundle area, an equivalent uniform modal weighted velocity, such as that defined in ASME Sect. III Div. 1 Appendix N, Article N-1300, shall be considered in the vibration analysis.

8.3.4 Tube Supports

● a) Unless otherwise specified by the Purchaser, Tube support spacing shall comply with API 560.

b) Individual tubes shall be supported and guided in a robust and satisfactory manner so as to prevent distortion (lateral or sagging) and damage due to expansion, fretting or vibration of the tubes.

c) Tube bundles may be bottom supported or suspended.

d) Tube bundles shall not rest on internal insulation or cladding.

e) The tube bundle shall be designed so that detrimental mechanical forces due to thermal expansion of the tubes or their supports are eliminated for all specified conditions including dry running when specified.

f) The tube supports shall be capable of supporting the weight of the tubes filled with HTM as well as withstanding stresses resulting from thermal expansion. Loads occurring due to hydraulic pressure testing shall be considered. Load calculations shall assume a minimum metal-to-metal friction co-efficient of 0.3.

● g) Unless otherwise specified by the Purchaser, loads determined for support of beams shall comply with ISO 19902.

h) Sheer loads shall be resisted by continuous members only. For example for tube sheets the sheer load shall be taken in the web of the tube sheet and not by stiffeners unless they are continuous in the direction of the sheer load.

i) Tubes shall be supported such that cyclic stresses will be kept below the maximum allowable cyclic stress value for the tube material.

j) The tube support shall not be welded directly on the tubes.

k) When tubes are supported by the fins, at least five fins shall rest on the support.

l) Tube supports materials shall be suitable for the maximum TEG temperature and be of fully killed pressure vessel quality. The use of dissimilar materials within one component or components connected by welding shall be avoided to eliminate problems associated with differential thermal expansions.

● m) Unless otherwise specified by the Purchaser, basic allowable stress for tube sheets shall be as follows:
   (i) For constant load, the basic allowable stress at the tube support design temperature level shall comply with ASME IID or ISO 13704/API 530.
   (ii) For a combination of constant Load and occasional load (e.g. friction or earthquake), the basic allowable stress shall comply with whichever is greater of 2/3 yield stress or the stress level at the tube support design temperature according to ASME IID or ISO 13704/API 530.
   (iii) With FEM analysis; based on the design temperature, the specified design life and the specified number of start stops; the allowable stresses shall be taken from ASME IID and shall follow the rules of ASME VIII div 2. Consideration of the combination of applicable load stress and thermal stress shall be given. Temperature gradients used in the analysis shall consider local cooling effects such as those derived from CFD analysis (Appendix A).

● n) The design and manufacturing tolerances of the tube supports shall ensure that each tube at each support point is appropriately supported. If the tubes are supported directly on the tube wall, the opening in the tube sheet which accommodates the tubes shall have a smoothed surface and carefully deburred/rounded edges to prevent the damage to the tube wall.

8.3.5 Tube Fins

a) Fins are normally helically wound strip type of solid or serrated form.

b) Fin materials selection shall be based on the peak calculated tip temperature as listed in Table 1 of ISO 13705/API 560, para 7.2.2.

Material	**Studs**	**Fins**
	Maximum tip temperature	**Maximum tip temperature**
	°C	°C
Carbon Steel	510	454
2 1/4Cr-1Mo, 5Cr-1/2Mo	593	549
11-13Cr	649	593
18Cr-8Ni stainless steel	815	815
25Cr-20Ni stainless steel	982	982

Table 4 - Maximum fin tip temperatures

● c) Any other fin material selected for design criteria shall be approved by Purchaser.

d) Peak fin tip temperature shall be calculated using established methods and shall take into account the maximum heat flow with fouling as well as any HTM and gas flow imbalances.

● e) If dry running is specified by Purchaser, the peak fin tip temperatures shall be established accordingly.

● f) Unless otherwise agreed by Purchaser, fins shall be continuously high-frequency welded to the tubes.

g) Fin tolerances shall comply with those specified in the "International Standard for Dimensions, Tolerances, And Tests of High Frequency Resistance Welded Fins" available from finned tube Supplier.

h) When selecting fin density, fin type and tube alignment, the type of fuel to be fired in the GT shall be considered:

Fin Data	**Risk of Light Fouling** *Fuel NOTE 1*	**Ideal Conditions** *Fuel NOTE 2*
Minimum fin thickness, mm	1.5	1.25
Maximum fin density, fins/m	157	236
Maximum fin height, mm	16	25
Fin type	Solid	Solid or serrated (twisted)
Tube arrangement	In-line or staggered	In-line or staggered

Table 5 - Fin selection guidance

NOTE 1 - "Light fouling" may occur with sour fuel gas or occasional light oil firing on the GT (back up fuel only, < 2 % of operating time) and when the solids concentration (soot) in the flue gas is less than 0.2 mg/m3 in dry flue gas corrected to 3 % oxygen.

NOTE 2 - Ideal conditions apply when the fuel gas is sweet (i.e. zero sulphur) and there is no provision for oil firing.

8.3.6 Tube Bundle Headers

a) If dry running is not specified, the design temperature for inlet and outlet header shall be the HTM maximum operating temperature plus 30K. However, where dry running is specified in most cases the headers will reach similar temperature to the tubes and hence shall be designed for the same design conditions as the tubes.

b) Headers shall be designed to allow for full expansion of tubes and permit accessibility for maintenance and for welding. Sufficient length shall be allowed on tubes in headers to permit cutting and re-welding of tubes.

● c) Tube to header weld detail shall be in accordance with the selected code, or where the code does not define details then the detail shall be agreed with the Purchaser.

d) Set-in type connections shall not be used when there is risk of fouling or corrosion from the HTM.

e) The headers should be designed to give a uniform flow and to achieve that, be sized so that the dynamic head loss is not more than 5% of the individual tube pressure drop. Where this results in uneconomic or impractical header size, a **higher pressure** loss (up to 10% of the individual tube pressure drop) may be accepted, but, in this case, the Supplier shall determine the effect of resulting mal-distribution and demonstrate this does not have a detrimental effect on the design and that resulting film and metal temperatures remain within allowable limits. These calculations shall be made available to the Purchaser upon request.

9. Dampers

9.1 General

- a) The Purchaser shall specify the requirements for TEG flow control into the WHRU, and the degree of WHRU isolation necessary for operational and maintenance purposes.

  b) Dampers are employed for the following functions:
  (i) Connection of the GT exhaust to a bypass stack during GT start-up to allow unrestricted GT start-up time,
  (ii) TEG flow regulation for WHRU start-up or control,
  (iii) Continued GT operation during WHRU shutdown,
  (iv) Thermal isolation of a shut-down WHRU during normal turbine operations.

9.2 WHRU Dampers

9.2.1 Damper and Isolator Types and Functions

The table below shall be used as guidance in the selection of dampers and isolators.

TYPE	FUNCTION	REMARKS
Multi-Louvre Damper (MLD)	**TEG flow control** **TEG isolation** **Stack isolation**	*ADVANTAGES* • Suitable for TEG flow control. • The downstream velocities across the duct quickly recover towards a uniform profile. • As each louvre is pivoted about its centre, TEG pressure and flow effects are balanced such that lower torques are required reducing the force requirement for actuation (see comments on actuator selection). • Faster emergency shutdown than a diverter damper. *DISADVANTAGES* • TEG leakage rates are inherently greater than the diverter-type as the total length of seals around each louvre exceeds that of the single blade of the diverter type. • The drive linkage shall include a mechanical interlock in order to assure certainty that the GT cannot be dead-headed. *NOTE* • *Can be used, in conjunction with other equipment, to achieve 100% isolation.*

TYPE	FUNCTION	REMARKS
Diverter Flap	**TEG isolation** **TEG flow control**	*ADVANTAGES* • Lower TEG leakage than the louvre-type owing to reduced seal length. • Provides certainty that the GT cannot be dead-headed as the blade cannot simultaneously block both exit paths. *DISADVANTAGES* • TEG flow control is less precise than MLD type owing to gas flow characteristic • Downstream velocity profile across the duct takes longer to recover. • As the drive shaft is along one edge of the blade, a high torque is required to overcome loads exerted on the blade by TEG pressure and flow. • Slower emergency shutdown than louvre dampers. *NOTES* • *Can be used, in conjunction with other equipment, to achieve 100% isolation.* • *A diverter is inherently larger than a pair of MLDs that would be otherwise needed. However two MLDs require intervening ducting so total weight may be similar.*
Integral Circular Damper	**TEG flow control**	*ADVANTAGES* • Are used in conjunction with circular WHRU configurations where nested helical tube coils are arranged in an annulus around the central TEG bypass. • The arrangement directs TEG into the annulus and / or through the integral bypass duct. • Provides certainty that the GT cannot be dead-headed as the damper cannot simultaneously block the inlet and bypass gas paths. • Provides a more uniform TEG distribution to the tube bundle coil. • Faster emergency shutdown than a diverter damper. • Promotes linear gas flow through the unit.
Spade plate bolted to duct flange	**TEG isolation**	• Simple, low-cost, device, but shall be fitted at a location where duct sections can be parted, (typically adjacent to an expansion joint). • Provides 100% flow isolation which may potential provide man safe access in conjunction with dampers. • The turbine must be shut down while the plate is inserted and removed. • Only used for prolonged periods of isolation due to time and labour required to install.

TYPE	FUNCTION	REMARKS
Guillotine slide gate (open top frame)	**TEG isolation**	*ADVANTAGES* • An open top frame Guillotine provides access to the blade, seal system and actuation system at all times when the Guillotine is in the open position. • Potentially provides "Man Safe" isolation in conjunction with seal air, subject to Purchaser's Health and Safety Policy. • With the WHRU Inlet louvre (or Diverter) closed and a seal air fan providing seal air between the louvre (or Diverter) and Guillotine, the Guillotine Blade can be lowered into the duct whilst the Turbine is still running. *DISADVANTAGES* • Heavier and more complex than a flange bolted spade plate, but can be closed more quickly • Requires limit switches to proven correct position for GT start which can reduce availability of the system.
Guillotine slide gate (fully enclosed)	**TEG isolation**	*ADVANTAGES* • Can be operated while the turbine is running. *DISADVANTAGES* • A fully enclosed Guillotine requires the Turbine to be shut down for access to the Blade, seal system and actuation system. *NOTE* • *Can provide 100% isolation in conjunction with seal air.*

Table 6 - Dampers and isolators types and functions

9.2.1.1 By-pass control

- a) By-pass control can be by diverter, louvre dampers, or integral circular.

    (i) The louvre or integral circular type shall be used if required to accurately control the TEG flow to the WHRU during normal operation.

    (ii) Fail safe position shall be bypass duct open and heating duct closed.

9.2.1.2 Isolators

a) Isolators that assure 100% TEG seal to the WHRU or by-pass may be either:
(i) Diverter damper with seal air system
(ii) Louvre dampers with seal air system
These isolators are not adequate to allow persons to enter the duct because of the possibility of accidental opening of the damper.

- b) Isolators that assure 100% seal for process and are Man Safe are subject to Purchaser's Health and Safety Policy. This isolation can be achieved by:
(i) Bolted Spade Plate
(ii) Guillotine slide gate with seal air system in combination with dampers.

9.2.1.3 Stack Dampers

a) Stack dampers have the following functions:
   (i) to conserve heat within the tube bundle when the GT is off
   (ii) to protect the tube bundle from rain ingress
   (iii) To contain fire extinguisher within the ducting
   NOTE: only considered when the HTM is flammable.

b) One or more stack damper blades should be designed such that high duct pressure drives to the open position, reversible when pressure declines in order to ensure that the GT cannot be operated against a closed Exhaust System. Alternatively they shall be interlocked with the diverter system to prevent dead-heading of the GT.

9.2.2 Damper and Isolator Design

9.2.2.1 Design Temperature

● a) If the Purchaser and/or GT Supplier have specified a duct design temperature, this shall be used for the design of damper.

b) If a design temperature is not specified the max TEG temperature shall be used.

9.2.2.2 Construction (all types)

a) Damper and isolator casing design, construction and internal insulation shall be generally to the same standard as the adjacent ducting.

b) Seal elements shall be of heat and corrosion resistant alloy such as Inconel 800.

9.2.2.3 Damper Insulation

a) The materials and fixing methods of the internal insulation shall be equal or better than that of the adjacent ducting. In order to avoid external hot-spots, the design shall minimise heat conduction via parts that penetrate the insulation.

b) No accessible external parts shall operate at temperatures hazardous to personnel.

c) No external parts shall exceed the appropriate hazardous area temperatures.

9.2.2.4 Damper Actuation

a) The actuator shall be designed for on/off, purge and modulating regulation and will normally take its operating signals from a controller (supplied by the Purchaser) with a temperature sensor in the outlet HTM pipe for each unit.

b) The actuator shall be fitted with a positioner and position transmitter wired back to a local accessible junction box.

c) When used for TEG flow control, a proven system shall be provided such that on power air pressure, hydraulic or signal failure the dampers move to the fail-safe position.

d) The actuator shall have override for manual operation.

e) Where man safe access is required the actuator shall have a manual locking device ensuring personnel safety during maintenance and inspection.

f) Actuators shall be selected to provide a suitable margin (typically 50 to 100%) over that required by the damper under the most severe operating condition.

g) Drive linkages, including shafts, shall be capable of transmitting at least 110 % of the maximum load that can be imposed on them by the actuator.

h) If a quick change-over is specified the Supplier shall ensure that the operating system is adequately designed , e.g. for pneumatic systems the Supplier shall advise the Purchaser the volume of air required to achieve this and agree how this is to be provided without adverse effect on the site compressed air supply.

9.2.2.5 Actuator Selection

● a) Damper drive may be by pneumatic, electric or hydraulic actuators. The selection depends on the size and type of damper.

b) When a suitable compressed air supply is available, the usual choice is pneumatic actuators because of cost and simplicity.

c) Pneumatically driven dampers may be either double-acting with fail-safe powered from an air reservoir or single-acting with fail-safe by spring-return.

● d) Unless otherwise specified by the Purchaser, auxiliary pressure parts, e.g. for pneumatic actuation the damper air reservoir, shall be designed and constructed in accordance with EN 13445 or ASME VIII Division 1.Each reservoir shall be provided with a vent, drain, pressure gauge, inspection opening, and be protected by a suitable safety valve. All pressure part calculations shall be submitted to Purchaser.

e)

f) To achieve very high thrusts (e.g. for large diverter dampers), the required diameter of a pneumatic actuator cylinder becomes very large. In this case a hydraulic system may be more practical. Hydraulic actuators operate at higher pressures than pneumatic, and thus achieve the required thrust with a smaller cylinder. The hydraulic fluid is also incompressible and hence there is no risk of “flutter” which can be an issue on large diverter flaps.

g) Hydraulically driven dampers may use a local or central hydraulic system.

h) The hydraulic cylinder shall be equipped with a lip seal.

i) The actuator shall include all necessary limit switches, positioners etc. inside a weather proofed casing.

j) The hydraulic system shall be equipped with radiation shield(s).

k) Electric drives are suitable for guillotine dampers. Electric drive can be used for bypass control, but it may be difficult to provide a fail-safe system.

9.2.3 Damper and Isolator TEG Leakage Performance

● a) The Purchaser shall specify the isolation requirements, and hence damper seal efficiency for the environment downstream of the damper(s).

b) The specified acceptable leak rate depends on the following:

(i) Heat loss only (energy conservation and pressure build up in the WHRU when operating via the bypass).

(ii) If a good bypass seal is necessary in order to utilise all available TEG in the WHRU.

(iii) Requirements for use of the MLD as part of a safe access system while the GT is operated via the by-pass.

(iv) Requirements to run the GT when the HTM is out of service.

c) The damper design and construction shall ensure that, within the specified service interval, actual leak rates do not exceed those specified.

d) For Bypass Dampers, the seal efficiency shall be:

(i) Better than 99.8 % on area for both the WHRU and by-pass stack (based on process considerations only)
(ii) 100 % for the WHRU if a safe downstream environment is to be created with the GT running.
(iii) For partial heat recovery applications where all specified operating conditions involve some TEG bypass and isolation is not required, i.e. only flow control function, then simplified damper seals may be acceptable.

e) For high sealing efficiency seals shall be all-metal, non-permeable and flexible, so as to accommodate expansion and movements of the damper and casing.
The Supplier shall state on the requisition the degree of TEG flow isolation, as a percentage of TEG flow at maximum load, provided by the damper type proposed.

9.2.4 Seal Air Isolation System

● a) When “zero-leakage” is specified, a seal air system shall be provided.

b) Sealing systems for diverter dampers shall comprise double seal around the perimeter of each blade with a cavity between the seals. Seal air is blown into the cavity at a pressure exceeding that of the duct.

c) Sealing systems for louvre dampers may be achieved either by blowing air into the space between two sets of dampers at a pressure exceeding that of the duct or a tandem louvre blade design where air is blown between the blade skins creating a complete air barrier within the blade.

d) 100% isolation may also be achieved by blowing seal air between the louvre damper and the guillotine.

e) A valve shall automatically isolate the air supply when seal air is not required to prevent backflow of TEG to the seal air fan/s.

f) The seal air fan shall be designed for a minimum pressure of 5 mbar at the injection point above the upstream duct pressure at a flow rate that can be expected at maximum worn seals at the damper blades.
NOTE: the duct pressure will vary with different GT operating conditions and the differential pressure across the closed damper may vary with seal deterioration.

g) The seal air system shall be instrumented to detect any seal leak or loss of air supply which result in lack of adequate differential pressure between the seal air and duct system (in which case a back-up fan shall be started).

h) Seal air fans shall be supplied as a set of two 100 % fans, i.e. duty/standby.

i) Each seal air fan volumetric capacity shall be at least twice the calculated seal leak rate to cater for in-service deterioration of the seals.

j) Seal air fan electric motors shall be selected to be ‘non overloading’.

k) Seal air fans shall comply with specified requirements for rotating equipment and electrical systems.

9.2.5 Damper Casing and Insulation

a) The damper casing shall be designed and constructed in accordance with the ducting specifications from this standard, e.g. for materials, construction details, pressure, temperature, insulation and cladding (hot or cold casing) duty.

b) The system of attachment of insulation and cladding shall be robust to ensure that attachments do not fail under service conditions. Supplier shall submit details of the attachment system and installation procedures for approval by the Purchaser.

9.2.6 Blades, Shaft and Operating Gear

a) Shafts, blades and seals shall be of robust construction and fabricated from materials suitable for the operating conditions.

b) Damper components shall be designed to prevent distortion or deterioration due to corrosion, high temperature or TEG flow conditions.

c) Components shall be designed to prevent vibration or fluttering at any blade position under any operating condition.

d) The damper system shall be designed for manual operation and the equipment supplied shall be easily accessible.

e) The damper system shall be equipped with a position indicator.

9.2.6.1 Blades

a) Blades shall not move under the effects of gravity, dynamic pressure or vibration, except when specifically designed to open under the influence of high static pressure in the duct (e.g. Stack Dampers).

b) The extremes of blade travel in both directions shall be detected by position switches.

c) The mounting brackets of the switches shall be adjustable so as to allow the closed positions of the damper blade to be set accurately.

9.2.6.2 Operating Gear

a) Linkages shall be outside of the ducting, and accessible for inspection and maintenance during normal operations.

b) Linkages shall operate correctly when the duct is displaced due to thermal expansion or wind.

c) Linkages shall be self-aligning and adjustable, with little or no maintenance.

d) Position switches shall be wired back to a local accessible junction box.

9.2.6.3 *Shaft and bearings*

a) The damper shaft shall extend through the duct wall to external bearings and shall be sealed to prevent TEG leakage.

b) The shaft seals can be a labyrinth of metal diaphragms to accommodate expansion, a mechanical seal or a conventional packed gland.

c) The damper shaft bearings shall be of the self-aligning and non-lubrication type. Materials shall be non-jamming (bronze) and can consist of replaceable pads.

d) The design shall ensure that the shaft at the bearing area is adequately cooled, sufficient to ensure that its rated temperature is not exceeded.

e) Levers shall be attached to shafts by means of sunken keys or rectangular ends.

f) Each shaft shall be marked to indicate the blade position. This mark shall be clearly visible during manual operation, and from grade level.

9.2.7 Requirements Specific to Damper Types

9.2.7.1 *Diverter Dampers*

a) Diverter dampers shall be provided with brackets for support from local steelwork, details to be agreed with the Purchaser.

9.2.7.2 *Multi-Louvre Dampers (MLDs)*

a) When a pair of MLDs is used for bypass control, a robust fail-safe (mechanical) interlock shall be included to ensure an open gas-path for TEG at all times.

b) MLDs may be supported from adjacent ducting.

9.2.7.3 *Removable Spade Plate Isolators*

a) The spade plate shall be provided with sufficient protection against corrosion, both in service and when not in use.

b) The spade plate may be manually inserted from the top of the ducting by means of suitable lifting tackle.

c) The lifting tackle may be assumed to be available as part of normal site maintenance equipment and shall not form part of the isolator supply.

- d) Each Purchaser or the Contractor shall provide a suitable overhead support and means of access for the lifting tackle. While not in use the spade shall be safely and securely stored locally, preferably above the duct.

9.2.7.4 Guillotine Slide Gate

a) A guillotine slide gate may be similar to a Removable Spade Plate, but with permanently installed operating gear and structural channel frames capable of supporting the assembly and handling the loads associated with opening and closing the assembly.

b) The slot in the duct to insert the spade during use shall be sealed with a flange and designed so that thermal insulation and/or purge system are sufficient to avoid overheating and hot spots.

c) Alternatively, the spade plate may be fully enclosed, enabling the plate to be inserted and removed with the GT operating. This arrangement may require careful design in order to ensure reliability of the position switches and drive mechanism.

d) Guillotine blades shall be of robust construction with adequate stiffening designed to prevent distortion at the maximum operating conditions (temperature and pressure).

e) Guillotine blade seals shall be metal leaf type designed to minimize leakage.

f) Guillotine drive mechanisms shall be either chain and sprocket type or worm drive type.

● g) To avoid risk of jamming:

(i) The mechanism shall drive both sides of the blade rather than from a single point.
(ii) The mechanism shall drive the blade in both the open and closed directions.
(iii) The driver and mechanism design shall include a large margin to overcome friction and dead loads (typically 200% excess capacity).

The Purchaser shall specify if manual or automatic operating is required. The drive should be by electric motor. Manual operation may be very labour-intensive and should only be considered if anticipated use is very infrequent. Where the system of the fully enclosed type manual operation shall not be used.

h) Position switches shall be provided to prove fully closed or fully closed.

10. WHRU Control Philosophy

a) This section describes the requirements for control and instrumentation systems and related valves and fittings for safe operation and the protection of the equipment.

● b) The Purchaser and the Supplier shall discuss and agree how the WHRU/s operation integrates with the GT/s operation under all defined operating conditions. This shall include WHRU hot and cold standby and start/restart modes.

10.1 Introduction

a) The safety and control equipment as well as its safety-instrumented functions shall fulfil the requirements of the IEC61511 "*Functional safety - Safety instrumented systems for the process industry sector*".

(i) Since the hazards and the required protection measures may extend beyond the scope boundaries (terminal points), then all mentioned activities should be performed jointly with the Purchaser's engineers.

NOTE: IEC 61511 is a technical standard which sets out practices in the engineering of systems that ensure the safety of an industrial process through the use of instrumentation. Such systems are referred to as Safety Instrumented Systems.

b) Prior to any start-up a GT/Exhaust System purge sequence shall take place according to NFPA 85, unless otherwise specified by the Purchaser.

c) The control and safety systems shall include the flow control inlet/bypass damper arrangement.

d) The control and safety systems shall also include the additional requirements, if any, specified in national or local regulations.

(i) The Supplier shall advise the Purchaser of any conflict between such regulations and the requirements specified above.

e) All necessary instrument process connections shall be provided by the Supplier regardless of who supplies the connected equipment.

(i) The Supplier shall advise the Purchaser the internal volumes of the various duct zones, so that the GT Supplier can calculate the necessary purge times.

● f) Purchaser shall define the format of analogue (e.g. 4-20 mA or digital) and logic signals. Damper Logic and analogue controls shall be supplied and configured by the Purchaser (or the GT Supplier) in a control system remote from the WHRU according to a controls description provided by the WHRU Supplier.

g) The Exhaust System Supplier shall include a local damper control panel. The local panel shall be configured by the damper Supplier such that in the event of either loss of logic signal or damper power (e.g. instrument air), the damper(s) are driven to the fail-safe position(s).

10.1.1 WHRU Controls Philosophy – Basic Mode

● a) The Purchaser shall define any variations to the following typical scope of supply:

(i) The analogue control signal to set the diverter damper system position is provided by the remote control system.

(ii) The logic control signal to enable the WHRU to operate and to move the damper as required during the GT start-up purge is provided by the remote control system.
(iii) The HTM flow is maintained constant by the remote control system.
(iv) The HTM temperature leaving the WHRU is controlled constant by varying damper position. Hence variations in WHRU performance at the different operating cases result in a change in the HTM temperature at the WHRU inlet.

b) The WHRU/ Damper purge logic and control logic is normally incorporated into the remote control system. It generates a permissive logic output for the WHRU to operate (i.e. loss of this signal triggers the dampers to fail-safe).

c) The HTM temperature controller is included in this remote control system. It generates an analogue output to:
   (i) Open and close the dampers as dictated by the logic system to achieve the start-up purge
   (ii) Position the dampers for normal operation.

d) When WHRU Inlet and Bypass louvre dampers are used, they are normally driven by a common actuator via a mechanical link.

● e) The Purchaser may specify that Inlet and Bypass are driven separately with a mechanical interlock to prevent simultaneous closure of both paths. If Inlet and Bypass louvre dampers are driven separately, they may be either share a common signal or use separate outputs from the common controller.

10.1.2 WHRU Controls Philosophy – Standby Units

● a) If the quantity of WHRUs to be supplied includes standby capacity, the Purchaser and the Supplier shall discuss and agree how load is to be reduced, i.e. run all units at lower load, or run fewer units at high load.

● b) If a WHRU is maintained on standby, Purchaser and Supplier shall discuss and agree how the HTM flow to the standby unit may be varied in the context of the degree of TEG isolation and the use of dump or trim coolers.

10.1.3 Signals

a) All analogue signal transmission to and from the WHRU / Damper system shall be of the 2 wire, 4-20mA DC type.

b) All signals used for prevention of fatality or major outage shall be redundant to ensure safety and availability. The applied redundancy shall allow for a “two out of three” 2oo3 configuration. Binary signals shall be provided on a dry contact and transferred thus:

Signal	Contact
Normal	active
Emergency	de-active status (fail safe)

Table 7 - Signal definition

10.1.4 Wiring, Junction Boxes and Protection

● a) All instruments and control system devices shall be adequately protected and weatherproofed to maintain an acceptable data transmission and integrity at the stated environmental conditions as noted in equipment data sheets or specifications.

b) All necessary interconnecting cable trays, conduits and junction boxes with appropriate electrical and weather protection shall be designed in accordance with project requirements and supplied pre-wired to agreed location and tested in accordance with the ITP.

c) Where a corrosive environment is specified, enclosures shall be fibreglass, stainless steel, galvanized, or epoxy resin painted.

d) Junction boxes shall be mounted at an accessible location.

● e) All necessary instruments for control, indication and protection of WHRU shall be provided in accordance with the Purchaser's requirements.

f) Supplier shall clearly indicate all the I/O signals from/to the WHRU, necessary to permit a suitable and safe operation, start-up and shut-down of the WHRU and the related accessories.

● g) All the instrumentation shall be suitable for the area classification stated by the Purchaser.

h) All instrumentation setting, connections and control systems shall be fail-safe.

● i) Unless otherwise stated by the Purchaser, all materials for process and pneumatic connections (tubing, compression fittings, manifolds, etc.) shall be included in the scope of supply.

j) Supplier shall show on a dedicated layout drawing the position of the junction boxes and the routing of the cable trays.

10.1.5 C&I Equipment

a) All instrument impulse tubing connections shall be arranged to avoid contamination or blockage by dirt or particles.

b) Whether or not the instrumentation is supplied within the Exhaust System scope of supply all necessary instrument process connections shall be provided by the Supplier.

c) Typical instrumentation requirements (see table below).

Instrument	Function	Supplied by (unless otherwise agreed)	Mandatory or Purchaser - Option
Position Switch – Bypass damper OPEN	To permit bypass purge	Exhaust System Supplier	M
Position Switch – WHRU damper OPEN	To permit WHRU purge	Exhaust System Supplier	M

Instrument	Function	Supplied by (unless otherwise agreed)	Mandatory or Purchaser - Option
Position Switch – Bypass damper CLOSED	To permit bypass purge.	Exhaust System Supplier	Needed if Inlet & Bypass louvres are not driven by a common actuator.
Position Switch – WHRU damper CLOSED	To permit WHRU purge	Exhaust System Supplier	Needed if Inlet & Bypass louvres are not driven by a common actuator.
Position Switch – Guillotine damper OPEN	To permit WHRU start or run. i.e. no blockage	Exhaust System Supplier	M
Damper Local Control Board with fail-safe system		Exhaust System Supplier	M
Tube skin metal temperature thermocouple and transmitter.	To indicate mal-distribution of HTM flows, blockage of individual flows and associated temperature increase. However such systemsmay be sensitive in operation and are potentially unreliable.	Exhaust System Supplier	O Quantity agreed between Supplier and Purchaser
Duct Connection for Pressure transmitter upstream of any damper		Exhaust System Supplier	O
Pressure transmitter	To trip GT if duct is blocked. Three (3) pressure transmitters or switches shall be installed in the TEG exhaust to indicate high pressure excursions, downstream GT discharge flange and upstream diverter or Multi Louvres Damper to trip GT if duct is blocked. One out of two “1oo2” voting logic for alarm, two out of three “2oo3” voting logic for trip. This shall be mandatory (M) if the exhaust duct/stack can be blocked.	Exhaust System Supplier	O
Flanged Branch, in WHRU exit duct / stack, with blind cover with chains Blind flanges shall be fitted with a threaded cap	Connection for temporary flue gas spot measurement equipment. Position shall take into account proximity of nearby equipment to ensure that a long probe can be inserted to traverse across duct.	Connection by Exhaust System Supplier	M
Temporary flue gas spot measurement equipment.	To fit Flanged Branch duct connection	Equipment by Purchaser	As required by local law.

Instrument	Function	Supplied by (unless otherwise agreed)	Mandatory or Purchaser - Option
Flanged Branch in WHRU exit duct / stack,	Connection for permanent continuous emissions monitoring equipment.	Connection by Exhaust System Supplier	
Permanent Emissions monitoring equipment.		Equipment supply to be agreed	May be required by national or local regulations.
HTM exit Temperature transmitter	To alarm / interlock on high temperature.	Purchaser	M
HTM exit Temperature transmitter	For HTM temperature controller	Purchaser	M
HTM Flow transmitter	Low flow alarm / interlock with WHRU running. Low flow alarm / interlock with WHRU bypassed (<100% damper seal)	Purchaser	M
WHRU exit duct Smoke detector	To initiate fire extinguishant, flammable HTM systems only	Purchaser	O

Table 8 - Instrumentation definition

d) Temperature measurements shall cover approximately 130% of the expected operating range and shall be protected with thermowells to allow maintenance in operating mode.

e) Pressure measurements shall cover approximately 130% of the expected operating range.

● f) The Purchaser shall specify the requirement for any instrumentation to be supplied for on-line WHRU lifetime calculation, including skin thermocouples to measure WHRU tube temperature/s.

g) End switches on MLD's shall be fitted to monitor the shaft(s) furthest away from where the actuator is connected as this detect failure on most (if not all) interconnecting linkages.

10.1.6 Process Side Valves and Piping

● a) These may be provided either by the WHRU Supplier or the Purchaser.

b) Flanged connections of valves shall comply with EN1759 or ASME B31.3.

c) Flange connections of valves 1 1/2" and lower shall be class 300 minimum, except that safety valve outlet flange rating may be class 150.

● d) Unless specified otherwise by the Purchaser, all valves shall be hand operated.

e) Discharge piping shall be provided by the Purchaser.

f) The following listed valves are typically required. Provision to vent and drain the tube bundle is always required. Where valves are fitted permitting the WHRU tube bundle to be isolated safety valves shall be fitted in accordance with the table below.

Location	Remark
Coil Safety Valve	The rating and setting of safety valves shall be in accordance with the specified code. All safety valve outlets shall be adequately supported to withstand the reaction forces generated while the safety valves are discharging. Safety valves shall discharge to a safe location. The safety valves shall be of the direct spring-loaded type with springs exposed to the open air, i.e. with open bonnets. Safety valves shall be provided with a lifting gear and clamp for hydro testing. If standby valves have been specified, to enable online testing, maintenance and calibration, an approved interlocking device shall be installed to ensure non restricted relief.
Coil Safety Valve. Additional requirements if the HTM contains water	The total relief valve capacity shall be based on the maximum possible heat input when isolating valves are closed. The maximum heat input shall take into account the maximum GT load. Discharge piping arrangement shall suitable for steam or liquid discharge.
Coil Inlet and Outlet Isolating valves	These shall be located in the nearest accessible positions. To achieve this, the valves may be a short distance from, but not out of sight of the tube bundle connections. These valves may be remotely actuator operated if automatic/remote start-up is specified by the Purchaser.
Coil Drain valve(s)	These shall be hand operated. Connection shall be at the lowest point in the bundle or headers. The drain connection and valve shall be a minimum of 50mm NB, but shall be sized to drain tube bundle contents within approximately 1 hour. The drain shall discharge to an HTM storage vessel The valve shall be accessible from a permanent platform; to achieve this, it may be a short distance from the tube bundle connection. This valve may be remotely actuator operated if automatic/remote start-up is specified by the Purchaser.
Coil Vent valve(s)	Connection shall be at the highest point in the bundle or headers. Size shall be a minimum of 25mm. The valve shall be accessible from a permanent platform; to achieve this, it may be a short distance from the tube bundle connection. The valve shall discharge to a safe location away from any work area. This valve may be remotely actuator operated if automatic/remote start-up is specified by the Purchaser.
Pressure gauge and valve	The branch connection shall be adjacent to the safety valve and fitted with an isolating valve. The isolating valve and gauge shall be properly supported and accessible from a permanent platform.

Table 9 – Tube Bundle Valves

11. Access, Inspection and Maintenance

11.1 TEG Path Access

- a) The Exhaust System shall be equipped with access doors and inspection hatches (openings) to facilitate inspection and maintenance philosophy specified by the Purchaser.

- b) The number and location of openings, and their function (maintenance and / or inspection) shall be agreed between the Supplier and the Purchaser based on the following guidelines:
  - (i) Avoid locations where the most unsteady TEG flow patterns are present. Access doors represent a discontinuity in the internal lining and insulation system and should therefore, be located in areas where the wall pressure fluctuations (due to unsteady TEG flow) are expected to be lowest.
  - (ii) Easy access from the outside.
  - (iii) In particular it shall be possible to visually inspect the following:
    - a) All duct and casing internally lined surfaces.
    - b) All WHRU tube bundles from either side.
    - c) All headers supports.
    - d) All damper blades, seals, shafts etc. - from either side
    - e) All silencers components - from either side
    - f) All expansion bellows.
    - g) Any flow straightening devices.

- c) Unless otherwise specified inspection/access doors may be either rectangular or circular type, 600 x 600 mm or 600mm diameter free opening minimum. Access doors may either be bolted and vertically hinged so that the doors swing open horizontally or bolted with a davit installed to facilitate lifting and removal of the door. Rectangular access doors shall be constructed with rounded corners with minimum radius of 50mm.

d) Openings such as observation ports for visual inspection from outside, or removable hatches for insertion of temporary instrumentation, may be located and sized to suit the specific requirements

11.2 WHRU

- a) Unless otherwise specified by the Purchaser, it shall be possible to access the following areas for the purposes of inspection, repair and maintenance without cutting into casings:
  - (i) All tube bundle return bends
  - (ii) All header connections, i.e. tubes, vents, drains, supports
  - (iii) Outside surfaces of end tube bundle supports
  - (iv) Sufficient inspection/access doors shall be provided upstream and downstream of silencers, diverters, louvres, WHRU tube bundle and any other component installed inside the ducting which needs visual inspection/maintenance, to permit an adequate view of representative tubes, louvre blades, damper, silencer panels, etc. Access doors shall also be suitable for the removal of silencer panels and any other component installed inside the ducting and that needs to be replaced.
  - (v) Fixed (non-temporary) platforms with ladders, safety cages, handrails and safety chains shall be provided for access to each inspection/access doors. Platforms shall also be required around the WHRU for inspection and removal/insertion of tube bundle for maintenance, and for access to all the components of the diverter and louvre system (i.e. control panel, bearing hoses, leverages, shaft, manual actuation, etc.).

- ● b) The Purchaser shall specify if it is required to be possible to insert suitable equipment to visually inspect header internal surfaces.

c) Provision for such inspection may be made by including an externally accessible blind flange on each header, or, by means of a removable pipe spool on the inlet and outlet connections.

d) Access to header boxes, WHRU free end and dampers for maintenance shall be provided.

e) Once the WHRU has been shut down and allowed to cool to ambient temperature, the personnel may enter the WHRU sections through the access doors provided. Site Procedures shall be established to ensure that entry to the WHRU is only possible once a confined space entry permit has been obtained, in order to ensure the safety of the personnel entering the unit.

- ● f) The Supplier shall state clearly any special provisions required for prolonged shut down for inspection and maintenance of the WHRU. Facilities for proper draining or blow drying which may be required to protect against corrosion during shut-down periods shall be considered and agreed with the Purchaser.

NOTE: It should be noted that some WHRU tube bundles, if configured with triangular tube pitch and horizontal flue gas flow, may not be naturally and fully self-draining, in these cases the Supplier shall provide a detailed complete draining and drying procedure.

g) Prior to entry into the WHRU ducting, the permit system shall ensure that all relevant risk to personal have been considered in line with appropriate risk assessments and local requirements.

h) These should include but may not be limited to:
(i) Gas testing to ensure correct oxygen level and lack of harmful gas.
(ii) That the GT start is prevented.
(iii) That any dampers or guillotines are interlocked in the correct position with no possibility to be change
(iv) Seal air systems as applicable are fully operational.
(v) Entry access watchman and system in place
(vi) Suitable safe access provided both
(vii) Adequate internal lighting.

i) If the units have been internally insulated with ceramic fiber which may be carcinogenic, personnel entering the heater should wear appropriate safety equipment. Please refer to ECFIA Code of Practice and Specific Material Safety Data sheets.

12. INSTALLATION

a) Installation refers to:
   (i) the assembly of the different modules of the Exhaust System with all its component parts
   (ii) the bolting of the Exhaust System to the receiving steel structure or the concrete foundation
   (iii) the connection of the Exhaust System with the GT outlet flange
   (iv) the connection of the Exhaust System bundles with the process piping
   (v) Installation of the instruments according to the hook up drawings and wiring to the junction box
   (vi) Wiring of the electric motors and of the lighting to the junction box

b) The equipment shall be in as few parts as practically possible and the design shall be made for easy installation.

● c) The Purchaser shall advise on installation method and equipment at site for the Supplier to adjust the size of each part for easy installation.

d) The Exhaust System Supplier shall issue an erection specification with a step-by-step installation sequence with reference to the relevant drawings.

e) For Exhaust Systems with internal insulation, which are delivered to site/yard in pre-insulated segments, the correct installation of insulation and lining system to cover the duct flanges after assembly of those is of immense importance for correct function and service life of the whole system. The design of the joints shall be undertaken by the Supplier during the engineering phase and all necessary components shall be supplied together with detailed instructions.

f) To ensure faultless installation of insulation and lining system, the Supplier shall issue a project-specific procedure with drawings and deliver all required parts and material (e.g. pre-manufactured liner segments, insulation, bolts, nuts, washers, seal weld procedure if applicable).

g) The erection specification shall have one section with regards to safe work handling and especially the need for certified lifting tools/jacketing equipment with the information regarding the overall dimensions, weights, location of the centres of gravity and the identification of the temporary supports, lifting lugs or bolt eyes to be used.

● h) The method of site assembly and sealing of the finished modules shall be agreed between the Supplier and the Purchaser. This shall either be done by seal welding with site installed liner cover or by bolting and gasketing only which may not prove such an effective joint but will minimize site installation effort and internal access required.

i) Finishing the modules using welding, forming or other machining operations on the assembly site shall be prohibited unless otherwise agreed. Working on the finished modules shall only be authorized if damage resulting from shipping and handling are found or in the case of design or fabrication errors causing fit-up problems. In this case a repair procedure shall be issued by the workshop from which the module originates. This procedure shall be approved by all parties involved.

● j) In the case of removable bundles, where agreed or required by the Purchaser the bundles may be delivered as separate items for installation into the WHRU casing at site.

k) It is strongly recommended that a representative from the Exhaust System Supplier be on site to supervise the installation. However, the documentation submitted shall contain sufficient information for the Purchaser to carry out the work. Only competent personnel shall perform the installation.

l) Installation activities include but are not limited to:

- (i) Check the packing on arrival against the packing list.
- (ii) Check the packing for any damage during transportation.
- (iii) Verify that the modules are properly stored on an even ground before installation
- (iv) Visually inspect the modules after the removal of the packing and before handling or lifting
- (v) Verify that the installation procedure is well understood by the workers through a training session and that all necessary tools (for instance torque wrenches) are available.
- (vi) Verify that the lifting equipment are in good working condition with all their certifications up to date and that the operators are qualified to use them.
- (vii) Verify that the slings and shackles are new or in good condition.
- (viii) Verify that the gaskets, bolts and nuts to be used are the ones specifically purchased for the installation.
- (ix) Ensure prior to installation that the position of the support points is such that the installed unit will match the connection to the GT within the tolerances of the expansion joint.
- (x) Supervise the installation of each module and check that the gasket between the modules flanges is properly installed.
- (xi) Verify that the insulation and lining system covering duct flanges which are mated at the assembly site, are installed correctly.
- (xii) Verify that the expansion joints are properly installed without lateral distortion, twisting or excessive axial elongation.
- (xiii) Verify that the dampers are properly installed according to the Supplier's instructions. It is of particular importance to ensure that the duct flange the damper will be connected to is level as distortions can affect damper sealing.
- (xiv) Verify that the flanges of the process piping and the header flanges of the bundles are properly aligned before putting the gaskets in place and bolting the flanges
- (xv) Verify the fixed point and the sliding points on the steel structure or the receiving foundation.
- (xvi) Check the verticality of the stack.
- (xvii) Apply touch up paint where the paint has been damaged.
- (xviii) Proceed to the final visual inspection internally and externally.
- (xix) Ensure that all transport security devices and temporary equipment are removed.
- (xx) Check that all the documentation has been supplied.

m) The Exhaust System Supplier shall detail any conservation measure to keep the equipment in good condition and avoid corrosion for the period of time between the end of the installation and the commissioning at the site of operation taking into account:

- (i) Transportation from the site of installation to the site of operation.
- (ii) The length of time (sometimes several months) between the end of installation and start up.
- (iii) The weather and environmental conditions at the assembly and operating sites.

n) If the loads during transportation/installation make temporary re-enforcements necessary (e.g. WHRU bundle, damper) which are to be removed before start-up, those shall be completely painted in red or yellow colour and removable without hot work or risk of causing damage to the equipment. They shall be shown on pictures in the installation procedure and it shall be described how and when during the installation sequence they are to be removed.

13. PRE-COMMISSIONING AND COMMISSIONING

a) The Pre-commissioning and Commissioning activities correspond to the final checks and tests of the Exhaust System to verify that it complies with its design and operational specifications and that it can be operated safely and trouble-free.

b) The pre-commissioning of the Exhaust System and WHRU shall be undertaken simultaneously with the pre commissioning of the GT and HTM circuit before they are started up.

● c) Pre-commissioning and Commissioning is a very integrated activity which requires the involvement of all the parties concerned with the Exhaust System Supplier, GT Supplier, Purchaser and any related subcontractors.

d) Although most of these activities take place after the fabrication of the Exhaust System they shall be planned and engineered well in advance in order to be executed in a safe and efficient manner.

e) In particular, the planning shall define where and when these activities take place.

NOTE: For instance where specified sub parts like the dampers can be partially or fully commissioned through a FAT in the sub Supplier workshop before the dampers are shipped to the installation site.
This test implies that the dampers are made fully operational in the workshop including the actuator, the actuator control and the sealing air system (fans with their electric motors, air receiving drum, air piping). This test shall demonstrate among other things:

(i) that both dampers are operating smoothly and in parallel (one opening the other closing) over the full range

(ii) that the safety position (bundle damper fully closed, bypass damper fully open) is reached within the required period of time, that the sealing air system-if installed- works and that blade seals of the bundle damper rest properly on their seats

f) The complete Exhaust System shall be partially or totally commissioned at the site of installation along with the commissioning of the GT.

NOTE: In that case it may prove difficult to commission the HTM circuit which usually involves a considerable flow rate. Moreover running the GT with the Exhaust System and without the HTM implies that the WHRU had been design to run dry or be fully isolated on the flue gas side which is not always the case.

g) In most of the cases the pre-commissioning and commissioning will be completed on the production site according to a specific health and safety program that takes into account the risks presented by live equipment (rotating machines, energized motors or instruments, noise, hot and/or toxic fluids) and the risks of simultaneous works.

h) Safety procedures shall be strictly adhered to.

i) Pre-commissioning activities are:

(i) Check that the complete Exhaust System documentation is on site
(ii) Check that the spare parts for commissioning and start-up are on site
(iii) Check that the special tools (for instance lifting frame for bundle removal) are on site
(iv) Remove all the temporary protection and supports still in place
(v) Perform an external and internal visual inspection of the Exhaust System. Check that no loose item may fall into the turbine outlet collector. Check that the blades of both dampers (bundle damper and bypass damper) are free to rotate over their full range without touching the insulation cladding of the adjacent modules. Check that there is no water resting on the bundle duct and bypass duct floors. Check with a lamp the good external condition of the bundles.
(vi) Cold stroking of the dampers

j) Commissioning activities:
   (i) Loop testing of any installed instruments and dampers control.
   (ii) Testing of safety alarms, interlocks and trips.
   (iii) Trigger the fail safe position of the dampers and check that it works properly.

14. PERFORMANCE TEST

- a) Once the plant has reached a stable operational regime corresponding to the specified design case, the Operator, Purchaser and Supplier of the Exhaust System shall, if required, undertake a performance test to verify that the performance requirements are met.

  b) The Purchaser and the Supplier shall agree the procedure for the performance test program based upon ASME standard PTC 4.4 Performance test code for GT heat recovery steam generators.

  c) As a minimum the following data shall be recorded for comparison with the requisition values:
     (i) HTM flow rate and inlet/ outlet temperatures to check the WHRU thermal performance
     (ii) HTM inlet and outlet pressure to check that the pressure drop is within acceptable limits
     (iii) TEG inlet and outlet temperatures
     (iv) TEG inlet and outlet pressure to check that the pressure drop on the TEG side is within acceptable limits

  d) If the TEG flow rate is not recorded via a flow metering instrument it shall be calculated by the GT Supplier.

  e) The performance test also gives the opportunity to make final checks normally executed during the commissioning but which could have been postponed for practical reasons.

  f) These checks shall include but are not limited to:
     (i) Infra-Red (IR) thermographic examination of the entire casing to detect hot spots. This examination includes the stack when it is insulated.
     (ii) Noise levels.
     (iii) Excessive vibrations or drumming of the casing.
     (iv) Abnormal displacements of the expansion joints and of the Exhaust System sliding point.
     (v) TEG leaks to the atmosphere (for instance near modules flanges gaskets or where the bundles headers nozzles pass through the casing).
     (vi) TEG sampling taken from the dedicated stack nozzle.

- g) The performance test is formalized through a report with a conclusion paragraph that shall summarize the corrective actions -if any- agreed upon between the parties.

APPENDIX A. APPLICATION OF COMPUTATIONAL FLUID DYNAMICS TO EXHAUST SYSTEM DESIGN

A.1. Introduction

The objective of this Appendix is to provide the Purchasers and Suppliers of exhaust duct systems with an overview of the use of CFD assessment in the design and assurance of exhaust duct systems. This is intended to inform the users of this document with respect to:

a) an overview of the key stages and processes within CFD analysis;
b) the types of analysis available;
c) the benefits of each method and how these can aid the design of exhaust duct systems;
d) the limitations, costs and level of expertise required;
e) what each method provides as output and requires as input; and
f) At what stages the various methods can be used within the design and verification process and what benefit they afford.

It is not the intention for this Appendix to provide detailed best practice for CFD analysis of Exhaust Systems. CFD best practice is a complex subject and is a function of the problem in hand (i.e. geometry and flow conditions) and availability of input data. As such, an understanding of CFD best practice is accrued through experience and cannot readily be distilled into a simple process to follow.

A.2. Benefits of CFD

Typically this kind of study would be expected to present a significant saving in terms of through-life costs from maintenance and replacement of failures in Exhaust Systems. Hence, CFD can be an attractive activity for Suppliers to help substantiate designs and demonstrate confidence in their long term performance. This can also aid Purchasers by providing a greater level of confidence in the performance of the acquired equipment and helping to differentiate between candidate Suppliers.
The upfront costs and timescales of CFD analysis need to be considered fully in the project plan, however, the initial outlay and effort can potentially save on future maintenance and downtime costs, which are typically one to two orders of magnitude higher.

A.3. What is CFD?

CFD is an important numerical technique in flow analysis (see Figure 1); whose use in design of exhaust duct systems is become increasingly more common given recent advances in computer power. CFD simulates the fundamental flow equations which describe the conservation of mass, momentum and energy (the Navier-Stokes equations). The flow path is divided into many discrete elements (usually into finite volumes) upon which the laws of conservation are applied.
Four key aspects of CFD analysis are: Geometry, Mesh, Boundary Conditions and Solver. These terms are defined in discussed in more detail below.

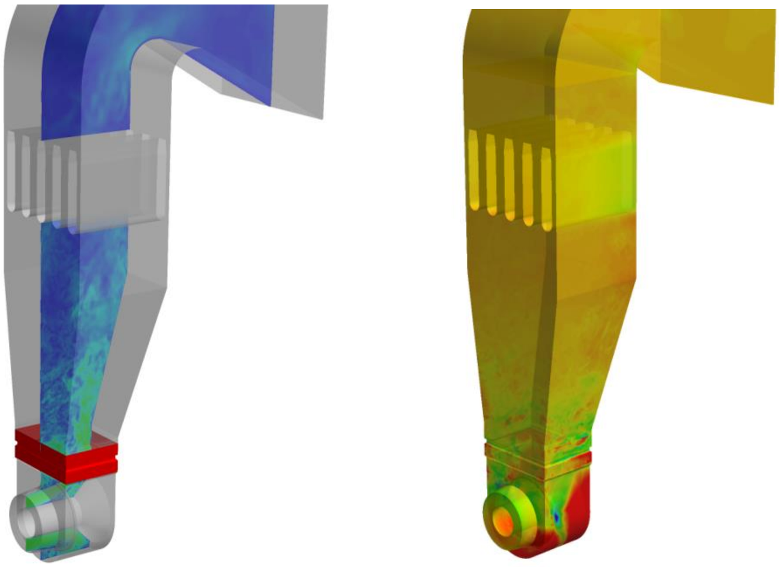

Figure 1 - Example output from a CFD analysis of an exhaust duct system showing instantaneous flow speed on a plane through the centre of the exhaust (left) and instantaneous pressure distribution on the internals walls (right).

A.1.1. Geometry

The geometry defines both the shape of the exhaust duct passages through which the exhaust gases will pass. Ideally, the geometry should reflect as closely as possible the as-built Exhaust System. However, it may be necessary to make some simplifications (e.g. removing small filters and fixing heads) to facilitate the construction of the computational mesh. Care should be taken during the design phase as small changes in geometry may have a significant influence of the resulting flow behavior.
The extent of the flow domain is an important feature in CFD analysis as the user must specify the flow conditions as inputs at the boundaries (see Boundary Conditions section below). If the flow domain is too small the boundary conditions may be too close to the region of interest and, therefore, may unduly influence or constrain the flow solution.

A.3.1. Mesh

The term *Mesh* (sometimes termed the *Grid*) defines the array of finite volumes (or *Cells*) which are used to divide the flow domain and across which the laws of mass, momentum and energy conservation are applied. Within each cell the flow properties (i.e. velocity, pressure, density and temperature) are assigned a single value. The computational cost of the analysis scales with the total number of cells. Therefore, there is a desire, where possible, to minimize cell count. However, if too few cells are used the resulting flow solution is likely to be inaccurate.
If an understanding of the likely flow pattern can be obtained *a priori* it is possible to optimize the mesh to improve the overall computational efficiency. For example, in regions of the flow domain where the gradients in flow properties are expected to be low it may be possible to reduce the local spatial resolution of the mesh (i.e. increase the cell size) without adversely affecting the results. Conversely for regions of complex flow (i.e. separated or swirling flow) the mesh resolution should be locally refined to capture these changes in properties faithfully. Used correctly, this technique can provide substantial savings in computational time compared to the use of a uniform cell size throughout the entire domain.
In practice, an understanding of the mesh construction and resolution which are most likely to be appropriate come through the experience of the CFD user in conducting similar analyses. However, upon completing a CFD analysis, it is advisable to check how the resolved gradients within the flow domain compare to those expected during the mesh construction phase. If necessary, the mesh can be further refined and the model resolved to provide an improved flow solution.

A.3.2. Boundary Conditions

Inputs to CFD analysis are made by the user in the form of specifying the flow conditions as inputs at the boundaries. For a model of the internal flow through the Exhaust System, these typically comprise definition of the distribution of flow velocities and temperature at the inlet to the Exhaust System and specification of the pressure at the outlet.
For a full thermal CFD simulation including the duct walls and insulation, the heat transfer conditions on the external surfaces will also need to be specified as will the thermal properties of the solid walls (i.e. density, thermal conductivity and specific heat capacity).
Although many types of CFD modeling are possible, each with differing levels of accuracy, often the user defined boundary conditions represent the largest degree of uncertainty in the calculation. This can limit the degree of accuracy obtainable with CFD modeling and should be taken into account when assessing the design against key performance criteria and considering the benefit of adopting a higher fidelity analysis approach.
Ideally, the flow domain should be terminated as far from the region of flow of interest or where the inflow or outflow conditions are benign (i.e. spatial gradients are low) or well characterized by available data. In practice, the application of boundary conditions is often limited by the availability of flow data and geometry and some comprises must be made. However, an understanding of these comprises is key when assessing the level of confidence which can be placed in the results of CFD analysis.

A.3.3. Solver

The term *Solver* describes the computational algorithms used to compute the flow solution on the mesh. Often the solver is integrated into a software package which also permits some or all of the following:

a) manipulation of the raw CAD geometry;
b) construction of the computational mesh; and
c) Visualization of the results.

There are many COTS CFD solvers available, most of which can accommodate the various types of modeling approaches relevant to exhaust duct systems.

A.4. CFD in Exhaust System Design

A.4.1. Uses of CFD

The flow within GT Exhaust Systems is typically highly three-dimensional, unsteady and at a high temperature. The complex nature of exhaust flow leads to CFD being used to characterize flow paths, bulk flow velocities, velocity fluctuations, pressure loss, pressure fluctuations, flow temperatures and dynamic forcing for structural design (static, quasi-static and dynamic loads).
Figure 2 presents a flow chart showing how numerical analysis methods such as CFD and FE analysis can be combined and integrated into the exhaust duct design process.
The first stage of this process is to define the exhaust duct geometry and flow conditions to be considered. This information feeds into a CFD assessment of the exhaust duct flow, which depending on which CFD method is utilized, results in the calculation of the unsteady or time-averaged internal flow field. This flow data alone is useful in the design and performance assessment of process equipment such as WHRU.
Where unsteady CFD assessments have been conducted, the resulting flow data typically comprises both the internal pressure and temperature fields. These data can be extracted at the internal surfaces of the exhaust duct and mapped across to a Finite Element (FE) model of the structure in order to calculate the stresses which give rise to high and LCF (see Figure 2). These results in turn feed into high and LCF assessments of the design and enable improvements to be identified or designs to be substantiated.
In addition to fatigue assessments, a combined CFD and FE approach can also be used to model thermal stresses during start-up and shut-down sequences by the inclusion of time varying boundary conditions to represent the flow from the GT.

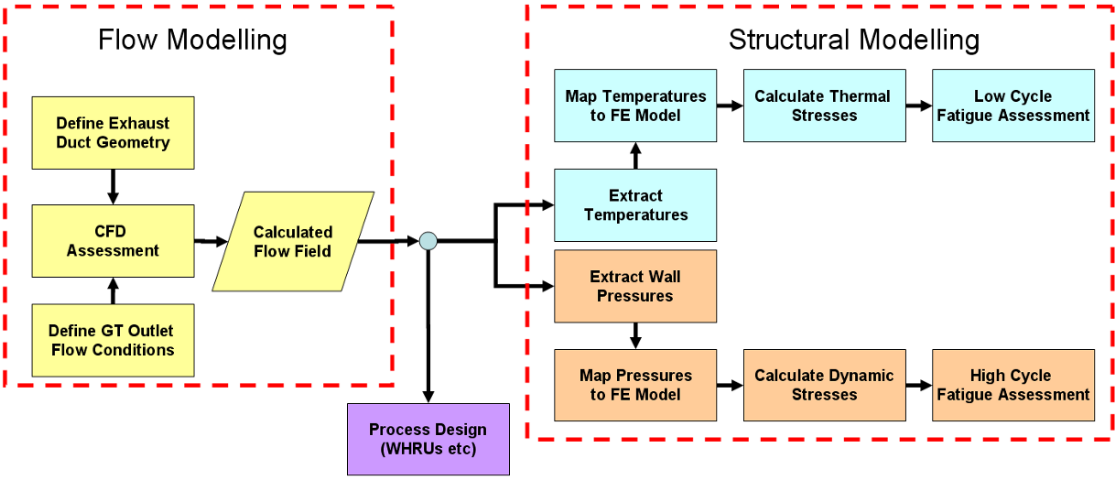

Figure 2 - Flowchart describing the use of numerical modeling in exhaust duct design

A.4.2. An Overview of CFD Methods

The greatest challenge to industrial flow simulation is the notion of *Turbulence*. Turbulence is commonly defined as quasi-chaotic fluctuations in flow variables (i.e. velocity, pressure and temperature) which are superimposed on top of steady and coherent flow behavior. These fluctuations generally act to smear out spatial variations in flow properties and tend to increase pressure loss and heat transfer.

In practice, the turbulent fluctuations are the results of the superposition of many individual vortex-like flow structures termed *Eddies*. The eddies present within turbulent flow span a wide range of sizes and timescales. The largest eddies are of the order of characteristic dimensions of the exhaust duct cross-section and are associated with large amplitude and low frequency (typically less than 10Hz) pressure fluctuations. The large eddies dissipate very little of their kinetic energy through viscous friction and eventually break up into smaller eddy structures. This process of eddy break up continues such that kinetic energy is transferred from the mean flow to large scale eddies and subsequently to successively smaller eddies. The smaller eddies are associated with lower amplitude and high frequency fluctuations in pressure and it is at these scales where the majority of kinetic energy is dissipated through viscous action into heat.

Theoretically, the governing equations of fluid mechanics (the Navier-Stokes equations) are a complete description of flow behavior when treated as a continuum, such that the turbulence effects described above can be explicitly simulated, this is termed DNS. However, it may be shown that the overall computational cost of DNS is impractical for most industrial flows, including those within Exhaust Systems, even with the World's fastest supercomputers. It is widely accepted that given the current rate of growth in computer power, DNS on an industrial scale will only become practical in 50-100 years from now.

Therefore, in order to conduct CFD for industrial flows, some assumptions must currently be made as to the structure of turbulence and its influence on the bulk flow behaviour. This is conducted through *Turbulence Modeling* which uses semi-theoretical and semi-empirical relationships to model some or all of the influence of the turbulence field and reduce the computational cost of the analysis. There are three common approaches which are:

a) RANS:
   (i) Uses a statistical model to represent the effect of turbulence on the flow.
   (ii) Determines the steady "mean" flow through the Exhaust System.
   (iii) Provides an indication of undesirable flow features (e.g. flow separation).
   (iv) Results can be sensitive to the choice of turbulence model.

b) URANS:

(i) Uses a statistical model to represent the effect of turbulence on the flow and provides a time-resolved calculation of the flow field.
(ii) Provides information on the likelihood of experiencing bulk flow instabilities within the Exhaust System; however detail of the broadband structural excitation is not accessible.
(iii) Can be used to examine changes in the flow and thermal field which result due to global changes in inflow conditions, such as start-up and shutdown transients.
(iv) Simpler to set up and cheaper to run than Scale Resolving methods (see below) but may be sensitive to the selection of the turbulence model.

c) Scale Resolving CFD Modeling:
   (i) Includes both LES and Hybrid RANS-LES approaches.
   (ii) Offer full resolution of unsteady flow and surface pressures and the results can be directly mapped across as inputs to structural assessments for fatigue life calculations.
   (iii) Impractical for the assessment of start-up and shutdown transients.
   (iv) This method is the most complex to develop, is sensitive to the model set up and has the highest computational costs.

Further details of the capabilities, limitations and implementation of these methods are provided in the subsections at the end of this Appendix.

A.5. Assessment Strategy

The type of analysis which is appropriate for a candidate exhaust duct system design will depend on a number of factors including:

a) similarity of the design geometry and load conditions to an existing in-service unit;
b) extent of input data available to conduct the assessments;
c) uncertainty in input data and load conditions;
d) degree of confidence the Purchaser requires; and
e) Timescales and costs.

In the event that the design and load conditions is identical to an existing in-service unit for which many hours of operational experience have been it may not be necessary to conduct a detailed CFD assessment.

Where the design changes are small, simple steady RANS analysis may be appropriate to confirm that the flow distribution into the WHRU bundle is acceptable and that gross flow separation is not likely to occur. Where this is indicated the same models can be re-run in a transient fashion (URANS) to determine the dominant frequencies of the fluid dynamic excitation and to review these in-light with the resonant frequencies of the structure.

In cases where the design is particularly novel or the load conditions are unfamiliar, then it may be appropriate to conduct a wide set of analyses to build confidence in the design in lieu of operational experience.

However, it is noted that most of the most advanced CFD methods require, as input, some upfront modeling with the lower fidelity methods in order to advise on appropriate spatial and temporal resolution and to provide a starting solution for the flow variables. Therefore, even the most advanced CFD assessments are progressive in nature with the opportunity to understand from the various tiers of analysis as the overall assessment proceeds.

A.6. Model Extent

Model extent is a key factor in Exhaust Systems modeling. The unsteady flow structures developed within an exhaust duct system are often strongly influenced by the flow turning within the power turbine diffuser and exhaust collector. The output flow from the collector can be highly non-uniform with areas of flow reversal (Figure 3).

Therefore, ideally a model would include the power turbine diffuser and exhaust collector upstream of the divergent exhaust diffuser. Using this approach it is often possible to assign simple uniform flow velocity and thermal boundary conditions at the power turbine diffuser inlet and the development of the flow through the collector, and the non-uniformity at the collector outlet will be explicitly resolved.

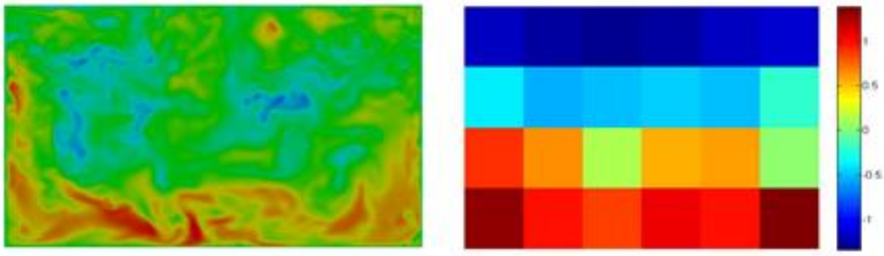

Figure 3 - Instantaneous velocity field at the divergent section of an Exhaust System calculated from Scale Resolving CFD showing significant distortion of the inflow (left). Typical normalised inflow velocity profile provided by a GT Supplier (right).

However, often the geometry of the exhaust collector is proprietary to the GT Supplier and/or is not available at the time of the analysis. If this is the case it is necessary to construct a truncated modelling domain which does not include the power turbine diffuser and exhaust collector. This represents the interface between the design remits of the GT Supplier and exhaust Supplier. However, the resulting challenge lies in the manner in which the inflow is prescribed for which two options are possible:

a) prescription of a uniform flow field normal to the inflow boundary; or
b) Prescription of a non-uniform flow field using information provided by the GT Supplier.

Examining Figure 3 it is seen that the flow field distortion at the collector outlet can be considerable. Therefore, the assumption of uniform flow is unlikely to be representative. Flow distortion maps, available from the GT Supplier, can be used to provide a first pass estimate of the non-uniformity of the outlet from the collector. However, this is often provided on a coarse resolution grid (Figure 3).

A further complication with Scale Resolving Methods is that they often require the use of an algorithm at the inflow boundaries to synthesize the incoming flow perturbations. In the case that the model extends back to the inlet to the power turbine diffuser the sensitivity to the choice of algorithm may be low as the majority of the flow unsteadiness which affects the upper sections of the Exhaust System are generated through the collector.

Models which include only the upper sections of the Exhaust System and are truncated at the collector outlet do not capture the incoming unsteadiness which results from the flow through the collector. These fluctuations will influence the flow behaviour in the upper sections of the Exhaust System.

In summary, the sensitivity of the results of the modelling to the model extent is not well understood. Therefore, in advance of the planned validation of CFD calculations for Exhaust Systems flow, it is advised that the model should include the collector geometry.

A.7. Information Requirements for CFD Analysis

In order to conduct a CFD analysis the following data is required as a minimum. The data list covers both flow and thermal assessments, for thermal assessments both sets of data are required.

a) Flow Assessment
   (i) geometry of the exhaust duct flow path including the collector;
   (ii) GT operating conditions to define mass flow rate, temperature and pressure; and
   (iii) Inflow velocity profile if the collector is not included in the model.
b) Thermal Assessment
   (i) geometry of the solid structure;
   (ii) material properties for all solids; and
   (iii) Ambient air conditions (temperature and wind speed ranges).

A lack of certainty in any of these data will influence the results. Furthermore, different elements of the data listed above are likely to be the property of the Purchaser, Supplier and GT Supplier which may influence the availability of the data. These factors should be borne in mind at early stages of the design such that the Purchaser and Supplier may review the input dataset and agree an appropriate analysis program.

A.8. Conclusions

This Appendix has given a brief overview of the use and benefits of CFD in Exhaust System design and the methods available. CFD is an advanced modelling technique and the costs associated with the analysis are not insignificant and need to be accounted for in the project plan. However, modelling of this kind can provide benefits to both the Supplier and Purchaser in terms of increasing the confidence that the delivered design is suitable for the duty. Therefore, the upfront costs of the analysis can be justified with the potential benefits in terms of lifecycle cost saving related to potential for reduced maintenance cost and potential down time.

The costs and timescales involved are small relative to the costs and timescales for Exhaust System procurement, installation and maintenance. Therefore, CFD analysis can provide benefits to both the Supplier and Purchaser in terms of increasing the confidence that the delivered design is suitable for the duty.

The selection of modelling appropriate is unique to each Exhaust System in that it is a balance between the degree of confidence required, complexity of the flow behaviour and availability of data. There is a natural cascade of model complexity which can be applied sequentially to develop understanding of the exhaust duct flows and identify requirements for additional layers of modelling fidelity. Often the simpler methods can provide initial screening for potential design issues and inputs to subsequent models.

A.9. Description of CFD Model Variants

A.9.1. RANS

RANS approach is a popular turbulence modelling approach used in industry and is normally applied to solve engineering flows. Each variable in the set of equations is split into time-averaged and fluctuating parts and the resulting equations are averaged over time. Reynolds Averaging introduces a number of additional terms into the Navier-Stokes Equations, which are termed the Reynolds Stresses.
Turbulence models aim to calculate the Reynolds Stresses based on other mean flow variables. A large number of turbulence models exist ranging from zero to multi-parameters models. No single turbulence model has to date been shown to sufficiently represent all flow scenarios and the CFD user must adopt the appropriate model, based on previous experience, experimental validation or by conducting sensitivity studies. Industry standard turbulence models are usually based on the conservation of two variables: turbulence kinetic energy and a dissipation term. The Reynolds Stresses are then related to these scalars by a number of generalized coefficients derived from simple experiments on turbulence.
The output from steady RANS models often interpreted as the calculation of the time-averaged flow behaviour, although strictly speaking the resulting prediction of the bulk flow behaviour assuming that the flow is steady. Steady RANS models can be useful to:

a) Identify regions of highly turbulent flow or flow separation which could potentially give rise to unsteady flow behaviour and cyclic pressure loading on the exhaust duct structure.
b) determine the levels of non-uniformity of the inflow into the WHRU bundle for input to the thermal design;
c) calculate the temperature field within the fluid and structure which can be used as input to a FE model to calculate the resulting thermal stresses; and
d) Verify the pressure loss through the Exhaust System.

Steady RANS models cannot be used to provide information regarding the magnitude of pressure oscillation or frequency content. However, steady RANS calculations are generally computationally inexpensive and can be completed in the order of a day once the model is built. Therefore, the results from steady RANS models can be used as a practical tool early on in the design process to advice on the requirement to conduct more complex analysis.
In the case that the need for more complex analysis is indicated, the results from Steady RANS models can be used to advise the solution set up or to the starting solution for more complex model variants to expedite the analysis.

A.9.2. URANS

The RANS formulation does not preclude analysis of unsteady flows and the Navier-Stokes equations may be averaged to preserve the time derivative of mean flow terms. This formulation of the equations is termed URANS. In this respect, the equations permit the simulation of the fundamental unsteady behaviour which is generally spatially coherent, of large magnitude and low frequency and, hence, is most of concern for flow induced vibration. Small scale and high frequency turbulent fluctuations are not captured by this method.
URANS modelling can be useful to:

a) Determine the magnitude and dominant frequency of pressure oscillations within the exhaust duct system, which can be compared against the resonance frequencies of the structure to assess the likelihood for high levels of vibration and fatigue to occur.
b) Calculate the temperature field within the fluid (and structure) during a start-up or shut down transient who can be used as input to an FE model to calculate the resulting thermal expansion and stresses. In this case the resolved fluctuations are more a function of the global variations in inflow throughout the transient as opposed to underlying flow unsteadiness.

Although URANS can in principle resolve the dominant unsteady flow structures, in some cases the natural levels of flow unsteadiness are insufficient to overcome the underlying turbulence model, which is dissipative in nature. In this case a steady solution can result although the model is solved in unsteady configuration. In this case more advanced CFD methods are required to resolve the unsteady flow behaviour.

URANS modelling generally uses the same CFD models initially constructed for Steady RANS. In the case that the fundamental pressure oscillations are of interest, the Steady RANS solution can also provide a useful starting solution for URANS, which helps to accelerate the analysis.

URANS analysis is typically an order of magnitude more computational expensive than Steady RANS. Using modern parallel computing URANS analyses typically take a few days to one week to complete.

A.9.3. Large Eddy Simulation

LES methods aim to explicitly capture the behaviour of the largest flow eddies whilst limiting the use of modelling to the smallest flow eddies. The largest eddies are generally of a similar length scale to that of the exhaust duct cross section and constitute the largest, most spatially coherent lowest frequency loading and, therefore, the improved resolution of these features provides benefit for flow induced vibration studies. Fortunately these eddies are the most computationally efficient to resolve. By contrast the smaller eddies are much more intensive to compute, but, are associated with lower magnitude and higher frequency loading and, therefore, can be represented with models without significant degradation of the solution.

LES requires very fine bespoke computational meshes and small time steps compared to those used for URANS. A simplified turbulence model is used to represent the transfer of energy to small scale eddies which are below the resolution of the mesh. The addition of the simplified turbulence model allows LES to use slightly coarser meshes than DNS (in which all important scales of turbulence are resolved).

Within LES methods the solution time increments defined by the user should be compatible with the characteristic time periods of the unsteady flow features of interest. As a result, LES is the only method of those discussed here capable of calculating the pressure loading across a wide range of frequencies (*Broad band*). By comparison URANS is generally only capable of resolving single frequency tonal components and their harmonics (*Narrow band*). In general, LES solutions take considerable time to settle into a state where the pressure oscillations are statistically robust; therefore, these methods are restricted to the consideration of steady operating conditions and are not appropriate for modelling start-up or shut down sequences.

A further complication is that turbulence is explicitly resolved as velocity fluctuations opposed to being calculated as a statistical quantity within the flow solution. Therefore, it is necessary to use an algorithm at the inflow boundaries to synthesize the incoming flow perturbations. Again there is benefit to placing the model boundaries as far upstream from the region of interest as possible such that the synthetic perturbations have time to develop in a physical manner (i.e. grow or decay) which reduces the sensitivity of the results to the choice of algorithm.

Whilst LES can be run using the models built for URANS, the mesh requirements are substantially different; therefore, results can be at best poor and at worst invalid. Therefore, these analyses are computationally expensive, complex to set up, take in excess of a week to complete on a modern parallel computer cluster and should only be undertaken by a CFD practioner with considerable experience in these methods. As a result, at present, these methods are most appropriate for the final verification of a design or for diagnosis of a flow induced vibration problem observed on an in-service system as opposed to parametric design studies.

A.9.4. Hybrid Methods

There are a variety of Hybrid methods, the most common being DES, and all in some degree couple LES and RANS approaches to turbulence modelling. This coupling is achieved such that where the mesh resolution is sufficiently fine the turbulent detail is captured explicitly with minimal modelling, as in the LES approach. Conversely, where the resolution is insufficient to capture the detail, such as near walls, the model returns to the full turbulence modelling approach of RANS. The aim of the Hybrid approaches is to provide methods which are intermediate to URANS and LES with respect to the level of computational effort required whilst maintaining the ability to capture the full broadband pressure spectrum.

In practice, although some saving on effort can be made, the cost of the solution is closer to that of LES than URANS. Hybrid methods often use algorithm at inflow boundaries in a similar manner to LES to describe the incoming turbulence. In some Hybrid method variants these algorithms are also required at the interface between the LES and RANS regions. Therefore, considerable experience is required with the specific implementation of Hybrid method to ensure that the interface between methods does not unduly influence the flow behaviour.

APPENDIX B. APPLICATION OF THERMAL AND STRUCTURAL ANALYTICAL TECHNIQUES TO EXHAUST SYSTEM DESIGN

B.1. Introduction

The intention of this document is to provide guidelines to the Purchasers and Suppliers of exhaust duct systems regarding the use of thermal and structural analysis in the design and assurance of such systems.

Operating experience indicates that there is significant evidence of premature equipment failure from temperature and stress related mechanisms (thermal fatigue) causing cracking, deformation and insulation breakdown with resultant hot exhaust gas leakage. Hence, there is increasing industry interest in the application of analytical techniques to underpin designs and provide robust documentary evidence for specified lifetime.

This appendix gives an example of how such methods may be applied with particular reference to NORSK standards.

B.2. Scope

This appendix covers the following Exhaust System equipment:-

a) Exhaust gas collector
b) Exhaust System inlet ducting
c) Exhaust System casing
d) Exhaust System outlet ducting
e) Exhaust System bypass ducting
f) Stacks

This equipment may be of either ‘cold’ or ‘hot’ casing designs, where, clearly, the former may be preferred as being significantly less vulnerable to thermal fatigue.

B.3. General

B.3.1. System of units

The following system of units should be used:

Length:	mm
Force:	kN
Mass:	kg
Acceleration:	m/s^2
Density:	kg/m^3
Pressure:	MPa (N/mm^2)
Stress:	MPa (N/mm^2)
Temperature:	°C
Temperature interval:	K

B.3.2. Design Class

Based on Norsok N-004 and the location of the Exhaust System, the ducting is generally considered to be of design class 4 or 5

B.3.3. Material

All ducting attachments and supports welded to the ducting shall be of the same material.

Materials of construction selection shall be as defined in this standard.

All bolts selection shall be as defined in this standard.

B.3.4. Material factors

Material factors in different load combinations are given in table 1 below.

Load combination	Material factor
SLS	1.0
ULS	1.15*
FLS	1.0
ALS	1.0

Table 10 - Material factors

*Material factor for bolts is given as 1.3

Basic Operational Loading

B.3.5. Self weight

The self-weight of the system should be calculated from the detailed design of the equipment. To ensure a conservative approach, a contingency factor of 10% should be added to the calculated self weight. If the equipment is weighed prior to the analysis, this factor may be omitted. To increase the loading from self weight in cases of mismatch between model weight and expected weight (e.g. due to removed details) in a FEM analysis, it is recommended to add point masses or scale the gravity acceleration applied. Altering of the density of the material in the FEM analysis should be done with care as this will change the thermal capacity of the structure.

B.3.6. Thermal

In the structural calculations, the loading due to thermal expansion shall be included. This may be applied through FEM analysis by performing a thermal analysis and importing the temperature profile to a structural analysis.
To determine the maximum thermal gradient, the minimum external temperature shall be combined with the maximum wind speed and the maximum design exhaust temperature.
To determine the maximum temperature of a cold casing, the maximum external temperature shall be combined with the minimum wind speed and the maximum design exhaust temperature.
The maximum design exhaust temperature should be 25K above the maximum operating temperature of the gas turbine.

B.3.7. Steady state

To apply the loading in a steady state thermal FEM analysis, it is recommended to apply a convection loading to both internal and external surfaces. Alternatively, the internal surface temperature may be assumed equal to the exhaust gas temperature. The steady state WHTC figures should be calculated from the flow pattern or preferably to be determined through a CFD and CHT analysis of the applicable system. The steady state external HTC should be calculated considering minimum or zero wind speed.

B.3.8. Transient

Due to the thermal heat capacity and thermal conductance, transient effects during start up and shutdown may temporarily increase the stress levels in certain parts of the structure. As the effect is mainly during start up and shutdown, it is mostly affecting the thermal fatigue (LCF) life. Hence, the transient thermal effects should be considered in areas where the thermal conductance and heat capacity may temporarily increase the thermal mismatch, e.g. at large brackets and at flanges.

As for the steady state analysis, the thermal loading in the transient analysis could be applied by convection. An alternative is to perform a CFD analysis with time dependent mass flow and temperature and couple the CFD analysis to a FSI analysis to determine the stress distribution throughout time. The transient curves describing the convection film figures and temperatures during start up and shutdown should be determined through CFD analysis or through measurements performed during operation of similar systems. Typical curves are shown in Figure 1 and Figure 2 below, as shown the temperature and convection rise from zero to idle very quickly and with a more gentle rise from idle to full power as the entire system heats up.

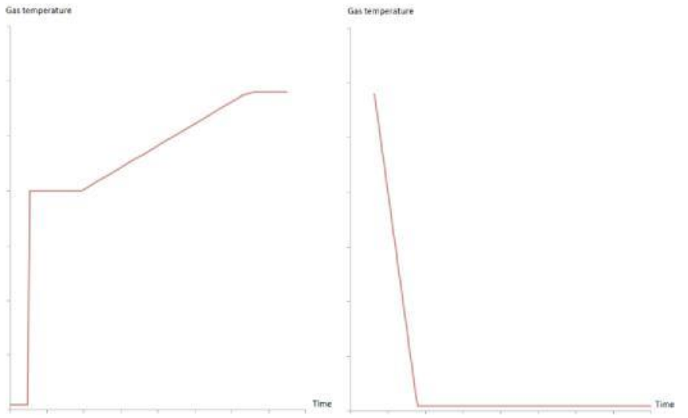

Figure 4 - WHTC during start up and shutdown

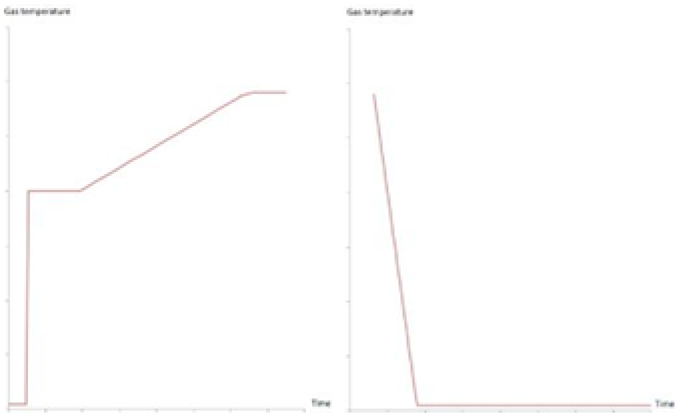

Figure 5 - Exhaust gas temperature during start up and shutdown

B.3.9. Pressure

The internal static pressure should be the calculated static pressure (e.g. through CFD analysis) applied with an added safety factor of 1.5 but shall be 50 mbar minimum.

B.3.10. Flow Linear Momentum

In cases where the flow direction is changed through the path of the ducting, the directional change of flow linear momentum will cause resultant force acting on the ducting. This thrust must be reacted by the external brackets. The flow linear momentum is given by the mass flow and the fluid speed. As the speed is a vector, the change of flow direction will cause a resultant force.

$$F = \dot{\mathrm{m}} \times \mathrm{v}$$

B.3.11. Wind

The environmental loading due to wind loading shall be calculated at the given elevation and the effect due to loading in any wind direction shall be evaluated. Shielding from other large equipment may be included. The wind speed at the given elevation should be calculated from the given wind speed at 10m above MSL using Norsok N-003. The wind speed at the given location should preferably be based on measurements. The wind loading shall be combined and coincide in direction and act simultaneously as the wave loading. Note that the maximum wind speed is the worst case for loading but the minimum wind speed is the worst case for external surface temperature.

B.3.12. Wave

At all installations on a floating structure, the effect due to wave motion shall be included in the analyses. The horizontal motion in any direction should be combined with minimum and maximum vertical loading. The motion characteristics shall be determined for the applicable position of the installation in each case. The stress due to wave loading should be calculated in any direction. The wave and wind loading shall be combined and coincide in direction and act simultaneously.

B.3.13. Snow and Ice

The additional loading effect due to snow and ice shall be evaluated for both on-line and offline conditions.

B.3.14. Vortex Shedding

Vortex shedding calculation according to EN 1991-1-4 shall be performed. Any possible vortex shedding issues might be further evaluated using CFD analysis.

B.3.15. Natural Frequency

In cases where the pulsation of the exhaust gas pressure might exite the natural frequencies of the exhaust ducting, a modal analysis shall be performed. The lowest applicable calculated natural frequency shall be at least 1.5 times the frequency of the exhaust gas from the turbine (typically 15-18Hz: however, a lower value could be generally expected). The analysis shall have the correct boundary conditions and pre-stress from the self weight of the ducting shall be included. In cases of calculated natural frequencies within the critical range, additional stiffeners increasing the natural frequencies should be evaluated carefully as the introduction of additional stiffeners might decrease fatigue life due to thermal loading (LCF). To evaluate the effect of frequencies within the critical range, a FSI analysis might be performed as input to a HCF analysis.

B.3.16. Creep

The maximum calculated steel temperature shall be evaluated and compared with the material creep data. If any calculated steel temperatures are within the creep range of the material, creep analysis shall be performed according to EN 13445-3:2009

B.4. Load combinations

The relevant load combinations according to Norsok N-001 and Norsok N-004 as defined below shall be calculated.

B.4.1. SLS

The design criteria for SLS combination are given as a maximum deflection of L/200, where L is the length between the supports. For a cantilever, L is twice the protruding length. (Norsok N-001). Since the criteria is a limitation in deflection, the combination is highly applicable for a cantilever exhaust stack, but in cases where the ducting is supported by a support structure tower, the load case is not applicable to the ducting itself. However, it should be separately evaluated as a part of the support structure calculation.

B.4.2. ULS

ULS load combination with the relevant loading shall be calculated in combination ULS-A and ULS-B with load factors as shown in table 2 below. The analysis should be performed in all applicable load directions. The wind loading shall be applied as a 100y, 3sec gust calculated according to section: Wind. Wave loading shall be applied as 100y wave motion. All loading with variable direction should coincide and be applied simultaneously.

Action combination	Self weight (Permanent)	Thermal loading (Deformation)	100y wind and wave (Environmental)	Internal pressure (Variable)	Flow linear momentum (Variable)
ULS-A	1.3	1.0	0.7	1.0*	1.3
ULS-B	1.0	1.0	1.3	1.0	1.0

Table 11 - ULS load combinations

*Refer to section: Pressure.
Hence no additional load factor in ULS-A should be applied.
The design criteria in ULS combination is given below:

$$\sigma < \frac{\sigma_{0.2}}{\gamma_m}$$

Where:
σ : Actual value of reference stress. Material $\sigma_{0,2}$: Yield strength
γ m : Actual material factor

NOTE: For hot casing systems, the deformation driven stresses due to thermal loading often result in calculated stress levels well above the criteria given above. To show that the critical stresses above the allowable origin from the thermal loading, linear analysis with the thermal loading excluded should be performed. As the thermal stresses originate from the prescribed thermal deformation of the ducting it might be less critical for structural integrity as any stresses from prescribed force loading. In such cases, plastic analysis of the system shall be performed to safely document that the structural strength is sufficient. LCF analysis shall be calculated in such cases to document fatigue life.

B.4.3. FLS

The Exhaust System shall be documented for a service life. In the FLS load combination, all load factors shall be considered as 1.0 (Norsok N-001), hence the maximum operating temperature may be applied in lieu of the maximum design temperature. The effect of LCF and HCF shall be calculated and if applicable be combined using Palmgren-Miner rule. It is recommended to use FEM analyses as basis for the fatigue calculations. Guidelines for analysis setup (mesh density, stress readout etc.) may be taken from DNV-RP-C203

B.4.4. LCF

The Exhaust Systems most prominent to LCF issues are hot casing systems. The extreme thermal loading of such systems result in large thermal gradients and hence stresses. Even though such stresses from prescribed loading may not impose any structural strength issues (see Section ULS) the repeated plasticity may impose LCF issues.
To evaluate the fatigue effect due to the thermal loading, LCF analysis according to EN 13445-3 chapter 18 of critical areas (e.g. flanges and large brackets) shall be performed for all hot casing systems. To include any transient effects, a transient thermal analysis describing the temperature profile throughout the loading cycle shall be performed and serve as input to the structural analysis. Calculated linear-elastic stress range or total strain range shall be used as input to fatigue analysis according to EN 13445-3.

B.4.5. HCF

Analysis of possible HCF from all applicable loading shall be performed. Loading that may impose HCF issues are mainly (but not limited to) fluctuating internal pressure and wave loading. When calculating HCF DNV-RP-C203 may be applied. Generally, for systems and details not single critical for structural integrity, a DFF of 1.0 is acceptable. Single critical details not available for inspection (e.g. covered by insulation) should incorporate a DFF of 3.0.

B.4.6. ALS

The following accidental loading may be applicable for gas turbine Exhaust Systems:

- Loss of insulation
- Fire
- Explosion

- Earthquake
- Extreme Environmental Loads
  (10.000y wind and wave loading)
- Platform Accidental Heel

All load factors and material factors shall be considered as 1.0 in the ALS condition according to Norsok N-001. The design criteria in an ALS condition are given by Norsok N-001 chapter 7.2.6. The functionality of the system might be impaired, but the ALS calculation shall ensure that the loading does not lead to total loss of structural integrity. The applicable nominal loading from permanent, environmental and variable loads shall be included in combination with the current ALS loading. The ALS check may be omitted if an overall evaluation shows that a collapse will not entail danger of loss of human life, significant pollution or major financial consequences.

APPENDIX C. INFORMATION TO BE PROVIDED BY PURCHASER

This section specifies the Purchaser-supplied information which should ideally be provided as part of a request for quotation (RFQ) for a complete Exhaust System. In the absence of relevant information the Supplier shall be entitled to adopt standard solutions in keeping with good practice as set out elsewhere in this standard and applicable statutory requirement.

C.1. General

1. Quantity of Exhaust System (total)
2. Quantity of Exhaust System working / standby
3. Tag numbers for main items of equipment
4. Thermal duty at design point for each Exhaust System unit
5. Location, e.g. Onshore inland, onshore coastal, Offshore Platform or Offshore floating
6. List of Nominated or Preferred Suppliers.
7. Any Purchaser requirements additional to those of this specification.

(Commercial information such as contact details, document submittal procedures, inspection requirements etc. shall be addressed elsewhere.)

C.2. Scope of Supply

8. A list of all items in the required scope of supply, including bolting and gaskets.
9. Battery limits.
10. Define Supplier services required for site erection e.g. site installation, supervision only, erection instructions only.
11. Define Supplier services required for commissioning e.g. commissioning, supervision only, commissioning instructions only.
12. State if any of the following items are to be included:-
    a. HTM local piping external to the WHRU. If required specify the design code.
    b. HTM local vent and drain piping
    c. HTM isolation valves
    d. HTM safety valves

C.3. Climatic and Imposed Loadings

C.3.1. Climate and Ambient Data

13. Maximum, normal and minimum ambient temperatures.
14. Humidity
15. Rainfall details
16. Snowfall/ice details
17. Especially stringent conditions, e.g. maritime environment, desert, dust, etc.
18. Altitude

C.3.2. Imposed Loadings due to Climatic and environmental effects

19. Wind maximum gust speed and directions and relevant code.
20. Earthquake zone rating and Soil factor occupancy factor and other relevant parameters
21. Snow load (including impact e.g. from ice if applicable).
22. For offshore applications the pitch and roll data during tow-out and operation
23. For FPSO or other floating sites, the pitch and roll data during operation and emergency conditions.

C.3.3. Imposed Loadings due to Mechanical effects

24. Live load
25. Interface loads (from turbine outlet flange)
26. Vibration levels
27. Imposed loading from structure

28. Blast loading (if any) with duration damage criteria, loading basis and other relevant parameters
29. Wind load requirements, e.g. Importance factor

C.4. GT Data

C.4.1. GT Details

30. Make and model of GTs.
31. Quantity of GTs.
32. Configuration of GTs and Exhaust Systems, e.g. unitised (one Exhaust System per GT), two GTs into one Exhaust System.
33. Gas turbine fuel type and analysis. Analyses shall state any sulphur content, since it is not always included in the exhaust gas composition and might have an effect on various aspects of the design (e.g. materials, finning, HTM temperature, stack)

C.4.2. GT operating data

A.1.1.1. Data to be provided for each operating case

34. TEG flow (design and maximum).
35. GT exit temperature (design and maximum).
36. Pressure (design and maximum).
37. TEG specific heat at relevant temperatures, or sufficient information for the WHRU vendor to derive same.
38. TEG analysis including any emissions.
39. If GT fogging is applied, resulting changes in TEG properties e.g. analysis, specific heat capacity at constant pressure, temperature shall be included in the TEG data.
40. Variability of the GT exit temperature over lifetime.
41. Start-up curve identifying peak gas temperature.

C.4.2.1. Operating details

42. The magnitude and frequency of load changes.
43. Variations in TEG flow with GT load.
44. Operation profile (frequency of hot, warm, cold starts; expected frequency of trips)
45. Expected lifetime e.g. (20 or 25 years).
46. Number of hours running per year.
47. Number of GT starts per year.
48. Number of Exhaust System starts per year.

C.4.2.2. TEG flow characteristics

49. Velocity profile of the TEG at the terminal point between GT and Exhaust System at start up, shut down, part and full flow conditions.
50. Table (or CFD output) that will specify radial component pulse of the GT at different loads.
51. Bleed valve influence on exhaust gas. Some provision needs to be made for design of flow corrective device during design stage (is usual more of an issue for industrial installations with radial exhaust, less problematic if exhaust is axial, although there have been some issues with some new GT types).

C.4.2.3. GT Interface: dimensions, orientation and elevation

52. Terminal details of the GT exhaust flange, to include dimensions, location, bolting.
53. Maximum allowable forces on the GT flange.
54. Movements of the GT exhaust flange to permit proper specification of expansion joint.

C.5. Exhaust System Thermodynamic Design

C.5.1. Design Operating case, Design requirements

55. If the thermal duty at more than one operating condition is specified, the Supplier shall determine which is the most onerous, and that shall be considered as the "Design Case".
56. Required Performance guarantees at the "Design Case" and any other cases.
57. Identify sufficient operating cases to define minimum and maximum heat recovery requirements, maximum gas temperatures and maximum exhaust flow and suitable intermediate conditions.
58. Heating Surface margin. State in percentage terms how much additional surface is to be provided over and above that necessary for the Design Case (if other than 10%, e.g. to reduce weight).
59. Outside Tube fouling factor. Purchaser may specify or may require the Supplier to determine based on TEG specification including any contaminants.
60. Inside Tube fouling factor. Purchaser may specify or may require the Supplier to determine based on HTM specification including any contaminants.
61. Maximum allowable static pressure at the inlet battery limit of the Exhaust System supply for operating and by-pass modes.
62. HTM Controlled temperature and allowable control tolerance at WHRU exit.
63. HTM temperature at WHRU inlet at design case.
64. HTM pressure at WHRU inlet at design case.
65. Provide HTM Product data sheet giving properties and specification, including specific heat, capacity, viscosity, thermal conductivity and density over applicable temperature range.

C.6. Utilities available

C.6.1. Instrument air (if applicable)

66. Instrument air pressures at local terminal point. Piping Design and max / normal / minimum operating.
67. Instrument air quality and dew point temperature.

C.6.2. Hydraulic Power Unit (if applicable)

68. Hydraulic fluid data sheet
69. Pressures at local terminal point for Piping Design and max / normal / minimum operating.

C.6.3. Electrical

70. Electrical supply for controls, solenoids etc.
71. Electrical supply for motors.
72. Define hazardous area zones.
73. Enclosure protection IP rating.
74. Electric motor specifications (if any).

C.7. Laws, Regulations, Codes and standards

C.7.1. Legal requirements applicable in the territory of the site

75. Applicable territorial laws, regulations, codes and standards, environmental standards.
76. Any special statutory or other regulations with which the equipment is required to comply.

C.7.2. Project Standards, for example

77. The name of the thrid party Inspecting Authority to be commissioned by the Purchaser,
78. The name of the Regulating Authority, e.g. PED, ASME.

C.7.3. International Standards

79. Pressure parts codes for tube bundle, external piping and damper air reservoir.
80. Other codes: e.g., for purge "NFPA 85: Boiler and Combustion Systems Hazards Code"
81. Electrical specifications for hazardous area.
82. Noise and vibration
83. Any preference for design codes for fatigue analysis if that is not addressed by the specified code. Note ASME provides little guidance on designing for cyclic operation. EN has some requirement for fatigue analysis.

C.8. Emission Control Equipment

84. Define requirements for Emission Control Equipment, e.g. NOx, CO, sulphur and particulates.
85. If Emission Control Equipment is not to be fitted during construction, state if space shall be allowed for later addition.

C.9. Mechanical Design

C.9.1. WHRU Tube Bundle Mechanical Design

86. Tube bundle design pressure.
87. Tube bundle design temperature.
88. Select option for Design Code for tubes and headers.
    a. Tubes and headers to ASME VIII, division.
    b. Tubes to ISO13704/API 530 and headers to ASME
    c. Tubes and headers to EN 13445 (not usual but also permitted).
89. If ASME Code is specified, select stamping options.
    a. Designed and constructed generally in accordance with ASME VIII, division 1, but without the ASME “U” Stamp.
    b. Fully compliant with ASME VIII, division 1, including the ASME “U” Stamp.
90. Select option for tube bundle arrangement.
    a. Staggered tubes (also known as triangular pitch). This is usually most economical with lowest tube surface, weight and cost, but some arrangements with triangular pitched hairpin coil are not fully gravity drainable
    b. In-line tubes (also known as rectangular pitch). It is easier to find leaks in an in-line arrangement.
    c. Supplier selection.
91. Select option for system mechanical design temperature and pressure.
    a. Tube bundle, casing and outlet ducting designed for maximum gas temperature in run dry, vented and drained condition.
    b. Tube bundle, casing and outlet ducting designed for maximum gas temperature in run dry, full design pressure condition.
    c. Tube bundle, casing and outlet ducting designed for local maximum metal temperature at under worst-case normal operation. There may also be a need for limited dry running for GT string testing.
92. Tube bundle material, i.e. tubes, bends and headers, fins and supports (if not to be selected by Supplier).
93. Corrosion allowances; inside tubes (HTM side), outside tubes (gas side) (if not to be selected by Supplier).
94. Additional NDT on tube return bends, e.g. to detect surface cracking.
95. Specify drain connection size, or use Supplier standard.

C.9.2. Welding and NDT

96. Welding code for tube bundle if not specified by the design code.
97. Welding code for ducting if not Supplier standard.
98. Any supplementary requirements (e.g. concerning welding qualifications)
99. NDT for tube bundle (if not 100%) together with any requirements for PMI.
100. NDT for ducting.

C.9.3. Casing and Ducting

101. Shape for ducts, rectangular or circular (if not to be selected by Supplier).
102. Exhaust System design pressure (if not selected by Supplier).
103. Exhaust System material, e.g. stainless steel (if not to be selected by Supplier).
104. External surface temperature limitations. (see also “Insulation”).
105. Exhaust System supporting requirements, e.g. number, type and location of available supporting system (steelwork or concrete foundations).
106. Design code/s to be used for mechanical design of Exhaust System casing, ductwork and supports, e.g. internationally recognised AISC or EN code, if not selected by Supplier.
107. Inspection hatches. Preferred locations and dimensions.

C.9.4. Bolting and Gaskets

108. Specify bolting and gaskets (if not to be selected by Supplier).

C.9.5. Expansion bellows

109. Specify type of expansion bellows, fabric or metal (if not to be selected by Supplier).

C.10. Insulation

C.10.1. Insulation location options

110. Specify insulation philosophy, if not Supplier selection.
    a. Internal insulation, hence cold casing steel.
    b. External insulation, hence hot casing steel.

C.10.2. Insulation materials

111. Specify insulation materials, if not Supplier selection
    a. Internal insulation,
    b. Internal insulation liner grade and thickness
    c. External insulation material.
    d. External insulation cladding material, e.g. SS grade, thickness

C.10.3. Attachment of Insulation and Liner or Cladding

112. Specify internal attachment method, if not Supplier selection.
113. Specify external attachment method, if not Supplier selection.

C.10.4. Insulation Performance

114. Specify the maximum allowed surface temperature based on area classification of insulated equipment.
115. Specify the maximum allowed surface temperature of accessible (within 1 m of platform or ladder) insulated equipment for personnel protection.
116. Specify the maximum allowed surface temperature of inaccessible insulated equipment for personnel protection.
117. The surface temperature of an insulated system is affected by the following. Specify worst-case conditions to be used; i.e. highest ambient temperature together with lowest wind speed at which the surface temperature limit is to be met.

C.11. Painting and coating

118. Paint specifications, e.g. Purchaser specification or Supplier selection.
119. Materials to be coated, e.g. carbon and low alloy steel external surfaces only.
120. Specify which surfaces shall be coated, e.g. un-insulated surfaces only
121. Colours.

C.12. Controls and Instrumentation

C.12.1. Controls Philosophy

122. Define any variations to the following typical scope of supply:-
    a. The analogue control signal to set the diverter damper system position is provided by the Purchaser's control system.
    b. The logic control signal to enable the Exhaust System to operate and to move the damper as required during the GT start-up purge is provided by the Purchaser's control system.
    c. The HTM flow is maintained constant and the HTM temperature leaving the WHRU is controlled constant by varying damper position to compensate for variations in GT load and user system heat demand. HTM temperature into WHRU will vary according to load.
    d. Purchaser shall define format of analogue and logic signals for controls interface, e.g. 4-20 mA.
123. If the quantity of Exhaust Systems to be supplied includes surplus capacity, Purchaser and Supplier shall discuss and agree how load is to be shared, i.e. run all units at lower load, or fewer units at high load.

124. If a Exhaust System or GT is placed on standby or for maintenance, define how the TEG is to be isolated and the HTM flow is arranged or varied; also and how and when the standby is put back into service.
125. If the HTM flow is not constant, define how is it controlled, and the magnitude and frequency of variations.
126. If the HTM is a hydrocarbon (liquid or gas) specify particular requirements if not vendor norms.

C.12.2. Instrumentation

127. State if any field instruments, wiring or hook-ups will operate in conditions more extreme than is specified for the ambient, e.g. located in high temperature area.
128. Standard instrumentation brand, or protocol (e.g. HART))
129. The format of analogue and logic signals.
130. Purchaser's requirements for field instruments supplied by Exhaust System Supplier.
    a. Tube metal skin temperature.
    b. Damper position transmitter
    c. Damper position switches in addition to those necessary to prove the purge.
131. Purchaser's requirements for process connections where the instrument is typically by others.
    a. Gas pressure before / after the tube bundle.
    b. Gas temperature before / after the tube bundle.
    c. HTM pressure before / after the tube bundle (if local HTM piping is included in scope).
    d. Gas continuous analysis point.
    e. Gas sample point with cap or blind flange.

C.13. Plant arrangement and supports

132. Preliminary Descriptions and/or General Arrangement drawings showing preferred plant arrangement. These shall indicate:
    a. The anticipated TEG inlet and outlet duct layouts and location of Exhaust System showing if the TEG gas flows through the WHRU vertically or horizontally.
    b. Outlet duct layout shall indicate client preference as to whether for the WHRU exit and bypass duct should connect to form a common discharge duct. If such data is not available then details of the area, available structural supports and required terminal points shall be provided to enable the Supplier to propose optimal equipment layout/s.
133. Preference (if any) for WHRU configuration e.g. vertical or horizontal gas flow, rectangular or circular shape.
134. Possible crane lifting capability at appropriate jib radii and movements shall be indicated.
135. Indicate available space for tube bundle removal, either vertical lift or horizontal pull as appropriate to the plant arrangement. If horizontal pull-out is preferred, indicate space available.
136. Indicate the location of any available platforms or steelwork to facilitate access for routine operation, maintenance and inspection.
137. Maximum allowable temperature at support points.
138. Predicted deflections at each support point in terms of mm/kN load.

C.14. Fabrication

139. Specify and particular requirements for the location and approval of fabrication facilities.

C.15. Transport and Installation

140. Delivery point.
141. Define any restrictions on transport, access and installation, e.g. weight and dimensions.
142. Maximum crane capacity and radius, temporary or permanent facility.
143. Any restriction on welding or 'hot work' on site

C.16. Inspection and Maintenance

C.16.1. Routine Inspection

144. Define if internal access to return bends or headers is required and how achieved, e.g. by lift-off panels or by cutting casing.
145. Define if access is by permanent or temporary platform.

C.16.2. Lifting and Handling Restrictions

Define any restrictions applicable to installation and maintenance:-

146. Permanent on-site crane capacity (weight and jib reach).
147. Manual handling restrictions.

C.16.3. Maintenance Philosophy

Provide the following information, or indicate if there is no preference:-

148. Define required availability.
149. Define how the tube bundle is to be maintained in the event of tube failure; i.e. WHRU replacement, tube bundle replacement or tube replacement.
150. State if the tube bundle shall be fully drainable. Note that this may affect tube bundle arrangement.
151. State the maximum period between scheduled major shutdowns for insurance survey, maintenance and inspection.
152. State the maximum period between scheduled minor shutdowns for minor works such as damper seal adjustment etc.
153. State the method for cleaning tube bundle heating surfaces (if any). Water washing may be specified when all insulation is external and WHRU duct arrangement is suitable for including drains.
154. Define access requirements, for example:
    a. Permanent access for routine activities, instruments, valves, and access doors.
    b. Temporary access for breakdown.
    c. Access to be possible for tube repair or isolation without cutting.
155. Define Inspection requirements, for example:
    a. Possibility to insert suitable equipment to visually inspect header internal surfaces
    b. Lifetime monitoring to optimise maintenance with any certification requirements.

C.17. Site Safety Requirements

156. Hazardous area classification.
157. Safety requirements regarding.
    a. Surface temperature.
    b. Grating.
    c. Emergency access.
    d. Height of steps.
    e. Earthing.

C.18. Ducting

158. Specify stack termination height.
159. Specify stack exit configuration, e.g. vertical or 45°.
160. Specify if there are any limitations on pressure drop or velocity.
161. Rain protection.
162. Specify if there is preference for minimum size and quantity of access doors.

C.19. Dampers and Isolators

C.19.1. Flow Control Damper

163. Select option for TEG flow control:-
    a. MLD type.
    b. Diverter damper (flap-type).
    c. Supplier to select.
164. Select option for damper actuation:-
    a. Pneumatic double-acting.

b. Pneumatic with spring return
c. Hydraulic (normally only used for large diverters).
d. Electric (only used for small dampers).
e. If electric, state if battery back-up is required for fail-safe operation.
f. Supplier to select.

165. Select option for MLD damper actuator:-
a. Single actuator driving both inlet and bypass louvres with mechanical.
b. Separate actuators on each MLD, with mechanical interlock to prevent simultaneous closure.
c. Supplier to select.

C.19.2. Damper air reservoir

166. When the damper actuation is by a pneumatic double-acting system, it is necessary to select a design code for the damper air reservoir. Select preference:
a. ASME VIII, division 1 without ASME Stamp.
b. ASME VIII, division 1 with ASME Stamp.
c. EN 13445 (not usual but also permitted).
d. Supplier to select.

167. If ASME Code is specified, select stamping options.
a) Designed and constructed generally in accordance with ASME VIII, division 1, but without the ASME "U" Stamp.
b) Supplied in full compliance with ASME VIII, division 1, and with the ASME "U" Stamp.
c) Supplier to select.

C.19.3. Isolation systems options

Standard flow control dampers do not provide leak-proof isolation. Specify the degree of isolation required as below.

168. Select degree of isolation required for the WHRU path:-
a. Standard Isolation; i.e. when the damper is closed, some leakage can be expected.
b. 100% isolation: i.e. seal air buffer in between double isolation.
c. Man-safe isolation: i.e., ducting is fully disconnected from the TEG supply, e.g. by breaking a flange and insertion of a fully bolted blanking plate.

169. Select degree of isolation required for the bypass path:-
a. Standard Isolation; i.e. when the damper is closed, some leakage can be expected.
b. 100% isolation: i.e. seal air buffer in between double isolation. Maximises TEG flow, hence heat recovery to the WHRU.
c. Man-safe isolation: i.e., ducting is fully disconnected from the TEG supply, e.g. by breaking a flange and insertion of a fully bolted blanking plate.

170. Isolation method.
a. Supplier to propose.
b. Purchaser preference. (Specify for each isolator position)

C.20. Noise limits and Silencer specifications

171. Permissible sound pressure levels at defined locations (near field or far field), for example:
a. Normally accessible work areas.
b. Accommodation facilities.
c. Plot boundary.

172. Silencer location(s), i.e. WHRU bypass duct and/or WHRU outlet duct.

173. Permissible Sound Power Level from stack.

C.21. Design processes

C.21.1. Analysis

Specify analytical requirements, for example:-

174. Structure global analysis.

175. Natural frequency analysis.

176. Vortex shedding.

177. Thermal insulation.
178. Vibrations.
179. Acoustic.
180. Pressure drops.
181. Flow / CFD.
182. Creep Fatigue.

APPENDIX D. FABRICATION AND WELDING

D.1. Fabrication

Supplier shall submit fabrication procedures and specifications covering all processes to the Purchaser for approval.

a) Equipment used in the manufacturing process shall be maintained to ensure that use, wear and failure do not cause significant inconsistency in the manufacturing process.

D.1.1. Identification

At all stages of manufacturing each piece or package of similar pieces of steel components shall be identifiable by a suitable system.

Pressure parts and primary structural steel shall be identified by inspection certificates.

Identification may be achieved as appropriate by batching or by the shape and the size of the component or by the use of durable and distinguishing marks applied in a way that does not produce any damage.

The following requirements apply to hard stamped, punched or drilled marks used for marking single components or packages of similar components, unless otherwise specified:

(i) they are permitted only for steel grades up to and including S355;
(ii) they are not permitted for stainless or low alloy steels
(iii) they are not permitted on coated materials for cold-formed components;
(iv) they shall only be used in the specified areas where the marking method will not affect the fatigue life.

If the use of hard stamps, punched or drilled marks is not permitted, it shall be specified whether soft or low stress stamps may be used.

Soft or low stress stamps may be used for stainless steels unless otherwise specified.

Any zones where identification marks are not permitted or shall not be visible after completion shall be specified.

D.1.2. Cutting

a) Cutting shall be carried out in such a way that the requirement for geometrical tolerances, maximum hardness and smoothness of free edges all as specified by the Supplier.

b) Known and recognized cutting methods are sawing, shearing, disc cutting, water jet techniques and thermal cutting.

c) Hand thermal cutting should be used only if it is not practical to use machine thermal cutting.

d) All cutting processes shall comply with the Supplier’s procedures and specifications.

e) If coated materials are to be cut, the method of cutting shall be selected to minimize the damage on the coating.

D.1.3. Shaping

a) Steel may be bent, pressed or forged to the required shape either by hot or cold forming processes, provided the properties are not reduced below those specified for the worked material.

b) Requirements and recommendations for hot, cold forming and flame straightening of steels shall be as given in the relevant product standards and in CEN/TR 10347. Shaped components that exhibit cracking or lamellar tearing, or damage to surface coatings, shall be treated as non-conforming products.

c) If distortion is to be corrected by flame straightening, this shall be undertaken by local application of heat, ensuring that the maximum steel temperature and the cooling procedure are controlled.

d) For flame straightening a suitable procedure shall be developed.

e) The procedure shall include at least:
   (i) maximum steel temperature and procedure of cooling allowed;
   (ii) method of heating;
   (iii) method used for temperature measurements;
   (iv) results of mechanical tests carried out for the process approval;
   (v) identification of workers entitled to apply the process.

D.1.4. Hot Forming

a) Shaping by hot forming shall conform to the requirements relating to hot forming of the relevant product standard and to the recommendations of the steel Supplier.

b) For steels supplied according to EN 10025-4 hot forming is not allowed.

c) For quenched and tempered steels hot forming is not permitted unless the requirements of EN 10025-6 are fulfilled.

d) Shaping by hot forming (Temperatures greater than 580°C) of cold formed thin gauge components and sheeting is not permitted if the nominal yield strength is achieved by cold forming.

e) For steel grades up to and including S355, the hot forming process shall take place in the red-hot state and the temperature, timing and cooling rate shall be appropriate to the particular type of steel.

f) Bending and forming in the blue heat range (250 °C to 380 °C) is not permitted.

g) For steel grades S450+N (or +AR) according to EN 10025-2, and S420 and S460 according to EN 10025-3, the hot forming process shall take place in the temperature range 750 °C to 960 °C with subsequent cooling at ambient air temperature.

h) The cooling rate should be such as to prevent hardening as well as excessive grain coarsening. If this is not practicable, a subsequent normalizing treatment shall be carried out.

i) For S450 hot forming is not allowed according to EN 10025-2 if no delivery condition is indicated. If no delivery condition is indicated, steel products S450 could be delivered in the thermo-mechanical delivery condition.

D.1.5. Cold Forming

a) Shaping by cold forming produced either by roll forming, pressing or folding shall conform to the requirements for cold formability given in the relevant product standard.

b) Hammering shall not be used.

c) Cold forming leads to reduction in the ductility. Furthermore attention is drawn to the risk of hydrogen embrittlement associated with subsequent processes such as acid treatment during coating or hot dip galvanization.

d) All cold formed pressure retaining parts that have been cold formed by more than 5 % fibre stress shall be subjected to an appropriate normalizing treatment and, if necessary, a tempering treatment.

● e) The allowable thinning of cold formed parts (e.g. tube bends) shall be specified.

f) The actual thinning after the forming process shall be measured for each piece and documented.

g) Appropriate NDT methods shall be defined which are able to detect any damage which the forming process might have caused. Each piece is to be checked by applying the specified NDT methods and the results shall be documented.

D.1.6. Drilling

D.1.6.1. Tolerances on hole diameter for bolts and pins

a) Hole diameters shall be consistent with good fit up and integrity of the final equipment.

D.1.6.2. Execution of drilling

a) Holes for fasteners or pins may be formed by any process (drilling, punching, laser, plasma or other thermal cutting) provided that this leaves a finished hole such that:
   (i) Cutting requirements relating to local hardness and quality of cut surface, are fulfilled;
   (ii) All matching holes for fasteners or pins register with each other so that fasteners can be inserted freely through the assembled members in a direction at right angles to the faces in contact.

b) Punching is permitted provided that the nominal thickness of the component is not greater than the nominal diameter of the hole, or for a non-circular hole, its minimum dimension.

c) Countersinking of normal round holes for countersunk bolts or rivets shall be undertaken after drilling.

d) For cold formed components and sheeting, slotted holes may be formed by punching in a single operation, consecutive punching, or joining two punched or drilled holes by use of a jig saw.

e) Burrs shall be removed from holes before assembly.

f) If holes are drilled in one operation through parts clamped together which would not otherwise be separated after drilling, removing of burrs is necessary only from the outside holes.

D.1.7. Assembly

a) Assembly of components shall be carried out so as to fulfill the specified tolerances.

b) Precautions shall be taken so as to prevent galvanic corrosion produced by contact between different metallic materials.

c) Contamination of stainless steel by contact with structural steel should be avoided.

D.1.8. Assembly Check

a) The fit between manufactured components that are inter-connected at multiple connection interfaces shall be checked using dimensional templates, accurate three-dimensional measurements or by trial assembly.

● b) Purchaser shall specify whether, and to what extent, trial assembly is to be undertaken. A method to ensure that the Exhaust System components fit together (e.g. trial fit) shall be proposed by the Supplier for the approval of the Purchaser.

D.2. Welding

a) Welding shall be undertaken in accordance with the requirements of the relevant part of EN 15614 or ASME IX as applicable.

D.2.1. Welding Plan

a) A welding plan shall be provided as part of the production planning.

b) Implementation of the welding plan shall include, as relevant:
   (i) The welding procedure specifications including welding consumable, any preheating, inter-pass temperature and post weld heat treatment requirements;
   (ii) Measures to be taken to avoid distortion during and after welding;
   (iii) The sequence of welding with any restrictions or acceptable locations for start and stop positions, including intermediate stop and start positions where joint geometry is such that welding cannot be executed continuously;
   (iv) Requirements for intermediate checking;
   (v) Turning of components in the welding process, in connection with the sequence of welding;
   (vi) Details of restraints to be applied;
   (vii) Measures to be taken to avoid lamellar tearing;
   (viii) Special equipment for welding consumables (low hydrogen, conditioning etc.);
   (ix) Weld profile and finish for stainless steels;
   (x) Requirements for acceptance criteria of welds in accordance with the Supplier's specifications.
   (xi) Cross reference to the ITP;
   (xii) Requirements for weld identification;
   (xiii) Requirements for surface treatment

c) If welding or assembly overlaps or masks previous welds special consideration is needed concerning:
   (i) Which welds are to be executed first and
   (ii) The possible need to inspect/test a weld before the second weld is executed
   (iii) The possible needs to inspect/test a weld before masking components are assembled.

D.2.2. Welding Processes

a) Welding may be performed by the following welding processes defined in EN ISO 4063:

   (i) 111: Manual metal-arc welding (metal-arc welding with covered electrode);
   (ii) 114: Self-shielded tubular cored arc welding;
   (iii) 121: Submerged arc welding with one wire electrode;
   (iv) 122: Submerged arc welding with strip electrode;
   (v) 123: Submerged arc welding with multiple wire electrodes;
   (vi) 124: Submerged arc welding with metallic powder addition;
   (vii) 125: Submerged arc welding with tubular electrodes;

(viii) 131: Metal inert gas welding; MIG-welding;
(ix) 135: Metal active gas welding; MAG-welding;
(x) 136: Tubular-cored arc welding with active gas shield;
(xi) 137 Tubular-cored arc welding with inert gas shield;
(xii) 141: Tungsten inert gas welding TIG welding;
(xiii) 21: Spot welding;
(xiv) 22: Seam welding;
(xv) 23: Projection welding;
(xvi) 24: Flash welding;
(xvii) 42: Friction welding;
(xviii) 52: Laser welding;
(xix) 783: Drawn arc stud welding with ceramic ferrule or shielding gas;
(xx) 784: Short-cycle drawn arc stud welding.

- Other welding processes shall only be used if explicitly specified.

D.2.3. Qualification of Welding Procedures and Welding Personnel

D.2.3.1. Qualification of Welding Procedures

a) Welding shall be carried out with qualified procedures using a WPS in accordance with the relevant part of ISO 15614-1 or ASME IX.

- b) If specified by Purchaser, special deposition conditions for tack welds shall be included in the WPS.

c) For joints in hollow section lattice structures the WPS shall define the start and stop zones and the method to be used in order to cope with locations where the welds change from a fillet weld to butt around a joint.

D.2.3.2. Welders and Welding Operators

- a) All welding shall be undertaken by qualified welders. Qualification tests for welders and welding procedures shall comply with ASME IX or EN 287-1or other code specified by the Purchaser.

b) Records of all welder and welding operator qualification tests shall be made available to the Purchaser upon request.

D.2.3.3. Welding Coordination

a) Welding coordination shall be maintained during the execution of welding by welding coordination personnel suitably qualified for, and experienced in the welding operations they supervise as specified in ISO 14731.

b) With respect to the welding operations being supervised, welding coordination personnel shall have a sufficient technical knowledge.

D.2.4. Preparation and Execution of Welding

D.2.4.1. Joint Preparation

a) Joint preparation shall be appropriate for the welding process.

b) If qualification of welding procedures is performed in accordance with ISO 15614-1, ISO 15612 or ISO 15613 joint preparations shall comply with the type of preparation used in the welding procedure test.

c) Tolerances for joints preparations and fit-up shall be given in the WPSs.

d) Joint preparation shall be free from visible cracks.

e) For steel grades higher than S460, cut areas shall be descaled by grinding, and verified to be free from cracks by visual inspection, dye penetrant or magnetic particle testing.

f) Visible cracks shall be removed by grinding and the joint geometry corrected as necessary.

g) If large notches or other errors in joint geometry are corrected by welding a qualified procedure shall be used, and the area shall be subsequently ground smooth and feathered into the adjacent surface.

h) All surfaces to be welded shall be dry and free from material that will adversely affect the quality of the welds or impede the process of welding (rust, organic material, paint or galvanizing).

D.2.4.2. Storage and Handling of Welding Consumables

a) The welding consumables shall be stored, handled and used in accordance with the Supplier's recommendations.

b) Welding consumables shall be individually marked and purchased from Suppliers who are currently acknowledged by bodies which independently test consumables (e.g. Controlas, Lloyd's Register of Shipping, American Bureau of Shipping, Det Norske Veritas,Bureau Veritas and CE Notified Bodies).

c) If electrodes and fluxes need to be dried and stored, appropriate temperature levels and times shall be fulfilled in accordance with the Supplier's recommendations.

D.2.4.3. Weather Protection

a) Both the welder and the working area shall be adequately protected against the effects of wind, rain and snow. Gas shielded welding processes are particularly sensitive to wind effects.

b) Surfaces to be welded shall be maintained dry and free from condensation.

c) If the temperature of material to be welded is below 5°C preheating shall be applied..

d) For steel grades higher than S355 suitable heating shall be provided if the temperature of the material is below 5°C.

D.2.4.4. Assembly for Welding

a) Components to be welded shall be brought into alignment and held in position by tack welds or external devices and maintained during initial welding.

b) Assembly shall be carried out such that the fit-up of joints and the final dimensions of the components are all within the specified tolerances.

c) Suitable allowances shall be made for distortion and shrinkage.

d) The components to be welded shall be assembled and held in position such that the joints to be welded are readily accessible and easily visible to the welder.

D.2.4.5. Preheating

a) Preheating shall be carried out in accordance with ISO 13916 and EN 1011-2.

b) Preheat shall be undertaken according to applicable WPS and applied during welding, including tack welding and the welding of temporary attachments.

D.2.4.6. Temporary Attachments

a) If the assembly or erection procedure requires the use of components temporarily attached by welds, they shall be positioned such that they can easily be removed without damage to the permanent steelwork.

b) All welds for temporary attachments shall be made in accordance with the WPS. Any temporary attachments may only be welded to the equipment with the express written permission of the Supplier.

c) If temporary welded attachments have to be removed by cutting or chipping, the surface of the parent metal shall subsequently be carefully ground smooth.

d) Adequate inspection shall be carried out to ensure that the constituent product is not cracked on the surface at the temporary weld location.

D.2.4.7. Tack Welds

a) Tack welds shall be made using a qualified welding procedure.

b) The minimum length of the tack shall be the lesser of four times the thickness of the thicker part or 50mm, unless a shorter length can be demonstrated as satisfactory by test.

c) All tack welds not incorporated into the final welds shall be removed.

d) Tack welds that are to be incorporated into the final weld shall have a suitable shape and be carried out by qualified welders.

e) Tack welds shall be free from deposition faults and shall be cleaned thoroughly before final welding.

f) Cracked tack welds shall be removed.

D.2.4.8. Fillet Welds

a) A fillet weld, as deposited, shall not be less than the specified dimensions for throat thickness and/or leg.

D.2.4.9. Butt Welds

a) All structural welds (also on non-pressure retaining items like ducting) shall be full penetration welds where technically possible.

b) The location of butt welds used as splices to accommodate available lengths of constituent products shall be checked for consistency with the design.

c) The ends of butt welds shall be terminated in a manner that ensures sound welds with full throat thickness.

d) Run-on/run-off pieces shall be used to ensure full throat thickness at the edge.

e) The weldability of such run-on/run-off pieces shall not be less than that of the parent metal.

f) After completion of the welds, any run-on/run-off pieces or supplementary material shall be removed.

g) If a flush surface is required, the excess weld metal shall be removed to satisfy the quality requirements.

D.2.4.10. Single Sided Welds

a) Full penetration welds welded from one side are normally applied for WHRU pressure part welds.

● b) Unless otherwise specified by Purchaser, permanent steel backing material may not be used.

D.2.4.11. Back Gouging

a) Back gouging shall be carried out to a sufficient depth to ensure full penetration into the previously deposited weld metal.

b) Back gouging shall produce a contour of a single U-shaped groove with its fusion faces readily accessible for welding.

D.2.4.12. Stud Welding

a) Stud welding shall be carried out in accordance with ISO 14555 or ASME IX.

D.2.4.13. Post-weld Heat Treatment

a) If heat treatment of welded components is necessary, it shall be demonstrated that the procedures used are appropriate.

D.2.4.14. Execution of Welding

a) Precautions shall be taken to avoid stray arcing, and if stray arcs do occur the surface of the steel shall be lightly ground and checked.

b) Visual checking should be supplemented by penetrant or magnetic particle testing.

c) Precautions shall be taken to avoid weld spatter.

d) Weld spatter shall be removed.

e) Visible imperfections such as cracks, cavities and other not permitted imperfections shall be removed from each run before deposition of further runs.

f) All slag shall be removed from the surface of each run before each subsequent run is added and from the surface of the finished weld.

g) Particular attention shall be paid to the junctions between the weld and the parent metal.

D.2.5. Acceptance Criteria

a) Welded components shall comply with the acceptance criteria as specified in the applicable fabrication code.

D.2.6. Welding of Stainless Steels

D.2.6.1. Amendments to EN 1011-1 Requirements

a) Contact pyrometers shall be used to measure the weld area temperature unless other methods are specified.

b) Temperature indicating crayons shall not be used.

c) WPQ records and associated WPSs that do not include a thermal efficiency factor in a heat input calculation may be used provided the heat input is adjusted in accordance with the appropriate thermal efficiency factor.

D.2.6.2. Amendments to EN 1011-3 Requirements

a) The required surface finish of the weld zones shall be specified.

b) It shall be specified if the coloured oxide films formed during welding shall be removed.

c) Due consideration should be given to corrosion resistance, environment, aesthetics and the implications of dressing off and cleaning the weld zone.

● d) Unless otherwise specified by the Purchaser, all slag associated with welding shall be removed.

e) After preparation of joint faces, oxidation, hardening and general contamination from thermal cutting processes may need to be eliminated by mechanically machining to a sufficient depth from the cut face. During shearing cracking may occur; these cracks shall be removed prior to welding.

f) Copper backing shall not be used unless otherwise specified.

g) Appropriate care shall be taken in the disposal of all post weld cleaning materials.

h) The approximate microstructure, which will form in the weld metal, may be indicated from the balance of ferrite and austenite stabilizing elements using a Schaeffler, DeLong, W.R.C. or Espy diagram. If used, the appropriate diagram shall be specified.

i) The Schaeffler, DeLong, W.R.C. or Espy diagrams may be used to indicate if the consumable will provide the correct ferrite content, taking dilution effects into account. If used, the appropriate diagram shall be specified.

j) Welded connections shall not be subject to heat treatment after welding unless permitted by specification.

D.2.6.3. Welding Dissimilar Steels

a) Weld connection of dissimilar materials shall be minimized.

b) Stainless steel nozzles or stubs (welded into the drum with a dissimilar metal weld) shall not be used.

c) However, if technically required, the requirements for welding different stainless steel types to each other or to other steels, such as carbon steels, shall be specified.

d) The welding coordinator shall take into account the appropriate welding techniques, welding processes and welding consumables.

e) The issues associated with contamination of the stainless steel and galvanic corrosion shall be considered carefully.

D.2.6.4. Nozzle Welds

a) All tube ends and pipe work shall be suitably prepared for welding where welding is required. The welding of all pressure retaining parts shall comply with the requirements of section 8.2.3.

b) Nozzle weld procedure and NDT shall be agreed with the Purchaser prior to welding. It is recognised that radiographic and ultrasonic NDE methods are not always possible for nozzle welds.

c) Nozzle welds that result in a small crevice such as set in welds shall not be used for corrosive fluids.

d) Set on welds shall be full penetration welds and root pass of set on nozzles shall be inspected for correct burn through.

e) PT or magnetic particle testing shall be applied to the cap of all nozzle welds.

f) For both set-in and set-on types, the fillet of the attachment weld shall blend smoothly with the drum, header and nozzle wall without any notch, sharp corner or undercut.

g) All inside edges of nozzles and connections, whether flush or extended, shall be rounded off to a minimum radius of 3 mm.

h) On double sided nozzle and header welds there shall be no crevices in between the welds.

i) Joints shall be made by welding; rolled or expanded joints are not permitted..

j) All tube ends and pipe work shall be suitably prepared for welding where welding is required. The welding of all parts shall comply with the specified code.

k) Socket-welded, single fillet-welded, expanded, brazed, riveted or screwed connections shall not be used.

l) Permanent backing strips shall not be used.

m) Flat heads or covers on headers shall be full penetration welded.

n) The fillet of all attachment welds shall blend smoothly with the header and nozzle wall without any notch, sharp corner or undercut.