

DEP SPECIFICATION

GAS TURBINE HEAT RECOVERY STEAM GENERATORS

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DESIGN AND ENGINEERING PRACTICE

DEM1



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1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for the design, materials, fabrication, inspection, testing, preparation for shipment, and erection of Heat Recovery Steam Generators (HRSGs) suitable for continuous operation in conjunction with a single gas turbine.

This DEP covers both unfired and fuel gas auxiliary fired HRSGs of both the forced and natural circulation types. It can be applied to both single-pressure and multiple-pressure HRSGs, but special arrangements such as integrated deaerators or low temperature condensate preheaters are not covered.

Although this DEP specifically describes HRSG for gas turbine applications, it can also be applicable to heat recovery units recovering heat from other (clean) processes. When this DEP is used for non-gas turbine applications, the user has to scrutinise and amend this DEP where required.

This DEP contains mandatory requirements to mitigate process safety risks in accordance with Design Engineering Manual (DEM) 1 – Application of Technical Standards.

This is a revision of the DEP of the same number dated February 2012; see (1.5) regarding the changes.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI, the distribution of this DEP is confined to Shell companies and, where necessary, to Contractors and Manufacturers/Suppliers nominated by them. Any authorised access to DEPs does not for that reason constitute an authorisation to any documents, data or information to which the DEPs may refer.

This DEP is intended for use in facilities related to exploration and production but, where required, it may also be used in oil refineries, chemical plants, gas plants, and supply/distribution installations. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process shall be implemented; this is of particular importance when existing facilities are to be modified.

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

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is 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 Principal may undertake all or part of the duties of the Contractor.

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

The **Principal** is the party that initiates the project and ultimately pays for it. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The capitalised term **SHALL [PS]** indicates a process safety requirement.

The word **should** indicates a recommendation.

Conflicts and deviations with respect to requirements and recommendations as mentioned in this DEP shall be tracked as a controlled record by the Contractor and reported back to the Principal throughout the project and are subject to approval by the Principal.

1.3.2 Specific definitions

Term	Definition
Attemperator	A system to control steam outlet temperature to a maximum temperature. Often it is also referred to as desuperheater.
Auxiliary Firing	Firing of fuel in the TEG system to supplement the heat input to the boiler. Some Vendors refer to auxiliary firing only if HRSG is operated on fresh-air and to supplementary or co-firing, if HRSG is operated on TEG. This DEP does not differentiate and refers to auxiliary firing for all firing that adds heat into the (flue) gases to the HRSG.
Boiler	Synonymous with steam generator.
Boiler Code	Design code of the boiler, specified by the Principal (e.g., ASME I or EN 12952).
CFD	Computational Fluid Dynamics
Co-Firing	Firing of fuel in the TEG to supplement the heat input to the boiler (see auxiliary firing)
Design Class	Design Class is a categorization defining fit-for-purpose facilities developed through Value Improvement Processes (VIPs) during a project Front End Development (FED) phase.
FAC	Flow Accelerated Corrosion
FAT	Factory/Functional Acceptance Test
Floor pressure	Lowest allowed steam pressure during continuous operation, could also be labelled minimum operating pressure
Fresh Air Operation	An auxiliary firing system which allows continued HRSG operation when the gas turbine is not in use. The air is provided by means of fan(s). Also referred to as Fresh Air Firing mode.
Fuel	All fuel gases specified by the Principal for firing in the boiler
GT	Gas Turbine, referring to the gas turbine engine, also known as combustion turbine
Harp	Heating surface with top and bottom header with tubes in between. Also known as panel or module.
HHWL	High High Water Level (trip)
HRSG	Heat Recovery Steam Generator
HWL	High Water Level (alarm)
IPF	Instrumented Protective Function (safeguarding by instrumentation)
LLWL	Low Low Water Level (trip)
LWL	Low Water Level (alarm)
MMVF	Man Made Vitreous Fibres
Maximum Continuous Rating (MCR)	Steam production under design conditions, measured upstream of any take-off of auxiliary steam and vent valve but downstream of any desuperheater.
NWL	Normal Water Level

Term	Definition
Peak Load	110 % of MCR, unless otherwise specified on the requisition
PEFS	Process Engineering Flow Schemes (also known as Process and Instrumentation Diagrams, P&IDs)
Requisition	Data/requisition sheets contained in DEP 30.75.10.94-Gen. (9 sheets)
RMS	Root Mean Square, a statistical measure of the magnitude of a varying quantity
Supplementary Firing	Firing of fuel in the TEG to supplement the heat input to the boiler (see auxiliary firing)
TEG	Turbine Exhaust Gas
TSOV	Tight Shut Off Valve
UEFS	Utility Engineering Flow Schemes (also known as Process and Instrumentation Diagrams, P&IDs)
WHRU	Waste Heat Recovery Unit

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section or clause number is shown in brackets (). Other documents referenced in this DEP are listed in (6).

1.5 SUMMARY OF MAIN CHANGES

This DEP is a full revision of the DEP of the same number dated February 2012. This document has been extensively revised and it is impractical to list all the changes here. The most significant changes are:

- More clarity on many requirements
- Additional requirements for application of duct burners

1.6 COMMENTS ON THIS DEP

Comments on this DEP may be submitted to the Administrator using one of the following options:

Shell DEPs Online (Users with access to Shell DEPs Online)	Enter the Shell DEPs Online system at https://www.shelldeps.com Select a DEP and then go to the details screen for that DEP. Click on the "Give feedback" link, fill in the online form and submit.
DEP Feedback System (Users with access to Shell Wide Web)	Enter comments directly in the DEP Feedback System which is accessible from the Technical Standards Portal http://www.shell.com/standards . Select "Submit DEP Feedback", fill in the online form and submit.
DEP Standard Form (Other users)	Use DEP Standard Form 00.00.05.80-Gen. to record feedback and email the form to the Administrator at standards@shell.com .

Feedback that has been registered in the DEP Feedback System by using one of the above options will be reviewed by the DEP Custodian for potential improvements to the DEP.

1.7 DECISIONS

A bullet (●) is shown in the margin of this DEP where further decisions or information are to be provided by the Principal or Contractor. Refer to Standard Form DEP 30.75.10.80-Gen. for recording decisions on the bulleted items indicated in this DEP.

Decisions related to the Design Class performance categories for HRSGs are beyond the scope of this DEP. Such decisions are intended to be made by the Principal in the project "Define" phase and detailed in project scope defining documentation e.g., equipment BDEP (Basic Design Engineering Package), project specific specifications, etc. HRSGs of any design class shall, as a minimum, adhere to Process Safety related requirements as specified in this DEP, unless derogations are approved by the Principal.

1.8 DUAL UNITS

This DEP contains both the International System (SI) units, as well as the corresponding US Customary (USC) units, which are given following the SI units in brackets. When agreed by the Principal, the indicated USC values/units may be used.

1.9 NON NORMATIVE TEXT (COMMENTARY)

Text shown in italic style in this DEP indicates text that is non-normative and is provided as explanation or background information only.

Non-normative text is normally indented slightly to the right of the relevant DEP clause.

2. DESIGN AND ENGINEERING

2.1 GENERAL

- 1. The Principal shall define general requirements such as:
 - a. Type of boiler
 - b. Indoor/outdoor operation
 - c. Mode of operation, i.e. continuous, intermittent, number of start-stops, etc.
- 2. The supplier shall be EFA/TAMAP supplier and show sufficient experience and recent references with similar equipment.
- 3. The design should be optimised to limit site activities and largest possible factory built modules but should carefully consider and comply with local limitations such as available plot space, limitation and transport dimension and weight, etc.
- 4. The HRSG shall comply with all performance requirements (flow, temperature, pressure) as specified on the requisition and any operating case that could have been foreseen by the Supplier based on industry practice and experience, such as e.g., partloads, start-up and shutdown.
- 5. All deviations of the Manufacturer/Supplier equipment from this DEP shall be listed by the Manufacturer/Supplier; and, this list shall be forwarded with the completed requisition.
- 6. The Manufacturer/Supplier shall comply with all local regulations. In case of conflict between local regulations and DEP, Vendor should inform Principal to agree on way forward.
- 7. The Manufacturer/Supplier shall provide a 3D model and follow DEP 30.10.05.11-Gen. for 3D model construction and review.
- 8. The Manufacturer/Supplier shall only utilise materials according to internationally recognised material codes and supply a clear list to the Principal for evaluation.
- 9. If local conditions include risk of freezing, either in operation or out of operation on any part of the boiler (including drain and vent systems and silencers), Manufacturer/Supplier shall include proper freeze protection.
- 10. The HRSG and related equipment shall be designed for a minimum life time of 25 years and 8000 hrs of operation per year.

2.2 MAJOR PRESSURE PARTS

2.2.1 General

- 1. The Principal specifies that either ASME Section I or EN 12952 shall be applied as the boiler design code to be applied to the main equipment.
- 2. The Manufacturer/Supplier shall obtain all code stamps and certificates required by local regulations.
- 3. The design, construction, inspection, etc. shall be in compliance with specified boiler code. Manufacturers own stamping in accordance with e.g., ASME PG-106 is deemed adequate.
- 4. The HRSG shall be designed to be operated at the maximum recommended concentration of dissolved solids, ion concentrations and conductivity in accordance with EN 12952-12 (i.e., operate continuously with the poorest allowable water quality).

2.2.2 Drums

- 1. Drum internals shall be fully bolted and fully accessible and cleanable without damaging the drum. Drum internals shall be designed to fit through the manhole when

- disassembled without cutting (i.e. unbolt only). All bolts/nuts shall be secured with tagweld or other means to prevent unintended unloosening of bolt/nuts.
2. Welds to drum, such as nozzles, tube stubs, fittings, mountings and any drum internal support shall be shop-welded only prior to heat treatment (i.e., they are also subject to heat treatment). No welding to drum allowed on site or after heat treatment.
 3. The size of the drum shall be determined by the following minimum requirements:
 - a. Minimum distance between NWL and LWL of 150 mm (6 in)
 - b. Minimum distance between NWL and HWL of 150 mm (6 in)
 - c. Minimum drum retention time (hold up time) between LWL and LLWL of at least 60 seconds assuming complete feedwater failure with drum at maximum steam production (peak load) and continuous blowdown at design rate.
 - d. Minimum response time between HWL and HHWL of at least 30 seconds assuming no steam flow, no blowdown and feed water control valve failed open or MCR (which ever is greater).
 - e. Minimum distance between HHWL and inlet of secondary separator to prevent any carry over of water into steam system shall be > 150 mm.
 4. The NWL, LLWL, HHWL shall be indicated on level gauge (after commissioning) with permanent mark.
 5. Feedwater supply to the drum and arrangement of steam-water separators shall be uniformly over the drum length.
 6. The steam drum shall have primary and secondary steam separators of sufficient capacity to achieve the required steam quality as reflected in the table below:

Pressure (Drum)		Minimum Required Efficiency	
(psi(g))	(bar(g))	(%)	Separation ratio
0-300	0-21	99.97	3500
301-450	21-31	99.97	3000
451-600	31-41	99.96	2500
601-750	41-52	99.95	2000
751-900	52-62	99.93	1500
901-1000	62-69	99.92	1250
1001-1800	69-124	99.90	1000
1801-2350	124-162	99.80	500
2351-2600	162-179	99.80	500
2601-2900	179-200	99.67	300

7. The drum(s) shall be accessible from both sides via elliptical manholes (minimum size 490 mm × 390 mm (19 in x 15 in)) that can be conveniently reached from platform.
8. Drum manhole covers shall open to inside (to assist proper closure) and be supported by adjustable hitches/davits.
9. Drum shall be equipped with external and internal handgrip above the manhole to allow for safe entry.

2.2.3 Downcomers

1. Downcomers shall be equipped with sufficient means, such as vortex breakers, to prevent vapour entrainment into downcomer, while still allowing for inspection.
2. Downcomer shall be foreseen with sufficient means to prevent foreign objects, nuts, bolts, etc. from falling into downcomer.
3. Heated downcomers (or any feeders of the evaporator that could be regarded as such) are acceptable, only if they are placed in low heat flux zones and if circulation is sufficient to avoid steaming in the downcomer under all conditions, including rapid pressure changes in the evaporator.
 - a. The downcomer shall remain free of vapour in steady state conditions at three times the calculated maximum heat flux.
4. To allow for internal inspection evaporator bottom distribution headers shall be equipped with welded nozzles of minimum DN 50 (NPS 2) and welded caps.
5. The inlet of the downcomer (in the drum) shall be flush with bottom of drum.

2.2.4 Attemperators (De-superheater)

1. The HRSG shall be supplied with attemperator(s) using spray water injection to allow for temperature control (limitation) of the desired steam temperature at the boundary limit.
 - a. If the boiler feedwater quality is of insufficient purity or contains non-evaporative components, the Principal shall provide injection water from a separate uncontaminated source.
 - b. Preferably, the location of the attemperation point should be in between two superheater sections.
2. To ensure complete evaporation of the spray water, the steam temperature directly downstream of the attemperation (desuperheating) point shall be maintained at a minimum of 25°C (45°F) above the local saturation temperature of the steam over the complete operating range (i.e., any possible operating case).
3. The steam temperature directly upstream and downstream of the attemperator point shall be confirmed by temperature measurements upstream and downstream of the attemperation point, to allow for monitoring and control. The following shall apply:
 - a. Downstream measurement shall be placed before entering the steam system or entering the next superheater section, but at sufficient downstream straight length from the attemperator point. (see Standard Drawings S 24.010 and S 75.004).
 - b. The thermal design of the boiler shall be balanced so that the attemperator spray water flow shall not exceed 15 % of the local steam flow at the point of attemperation, provided the injection water quality complies with the water specification as described in EN 12952-12.
4. Valve trim and nozzles materials shall be off material higher than SS400, with hardness > 40 Rc to prevent damage due to stellite corrosion.

2.2.5 Heating surfaces

2.2.5.1 General

1. Tubes banks shall consist of maximum ten (10) tube rows.
 - a. For evaporators not directly exposed to the maximum flue gas temperature, the maximum may be increased to fifteen (15) tube rows.
2. To minimise flue gas bypassing heating surface, the free space between casing and the nearest tube/fin tip in hot position shall not be larger than half the free space between adjacent tubes/fin tips in the rest of the tube bank (i.e., half tip to tip distance), with a maximum of 25.4 mm (1 in).

- a. If necessary, e.g., if a triangular tube pitch is used, strips, baffles or corbels may be applied to reduce the flow gap.
3. Restriction orifices and/or reduced drillings shall not be applied in the heating surface or any of the interconnecting piping of the heating surfaces. This also includes the evaporator circulation system.
4. Individual tubes shall be supported and guided to prevent distortion (lateral movement of more than $1.5 \times$ tube diameter) and damage due to vibration of the tubes. Tube wrap arounds (tube sheets) material shall be at least similar to the grade of internal lining materials as per (2.7.5.2).
5. Unless explicitly accepted by Principal, heating surface (tube banks) shall be top supported and not rest on internal insulation or cladding or casing. Construction and support shall allow for free thermal expansion in the downward and sideways directions.
6. The coils shall be designed so that no significant mechanical forces due to thermal expansion of the tubes or their supports can occur.
7. The maximum temperature difference, based on average tube temperature, between the first and last tube rows on a harp/module shall be less than 28°C (50°F).
8. Cross-over piping shall be inside the boiler casing and designed for the same (or higher) design temperature/pressure as the upstream header (in the steam/water flow direction). The number of casing protrusions shall be minimised.
9. Any welding in or connections to the heating surface (e.g., tube-to-header welds, pipes, and crossovers) shall not be exposed to high heat flux. If such connections are applied within the boiler casing they shall be located outside the main flue gas flow and shielded by a reasonable gas-tight construction of baffle plates and tube sheets.
10. The heating surface tube shall be one piece without any welding.
11. Only seamless tubes shall be used.
12. The following tube fouling factors shall be applied to determine operating metal temperatures and resulting design temperatures. These fouling factors do not need to be included in the thermal rating for the boiler. The Supplier shall be responsible for including sufficient fouling factors to achieve the guaranteed performance.

Economiser	$4000 \text{ W/m}^2.\text{K}$ ($705 \text{ Btu/h ft}^2 \text{ F}$)
Evaporator	$5880 \text{ W/m}^2.\text{K}$ ($1035 \text{ Btu/h ft}^2 \text{ F}$)
Superheater	$11760 \text{ W/m}^2.\text{K}$ ($2070 \text{ Btu/h ft}^2 \text{ F}$)

13. All heating surfaces and parts thereof, including cross overs/interconnecting piping shall be fully ventable and drainable.
14. Tube design shall be suitable for all operating conditions including start-up conditions, low flow and transient conditions.

2.2.5.2 Fin density and height

1. The maximum fin density, fin type, pitches and tube alignment (staggered or inline) depends on the type of fuel to be fired and shall comply with the following:

2.2.5.2.1 Clean gas in GT and or supplemental firing

1. If gas of sales quality (as typically found in public natural gas grids) or gases of equivalent quality, (free of solids and with an atmospheric dew point of at least -20°C (-4°F)) is fired, the following shall apply:
 - a. Minimum fin thickness $\geq 1.25 \text{ mm}$ (0.05 in)

- b. Maximum fin density ≤ 236 fins/m (6 fins per in)

2.2.5.2.2 Other gases and incidental light oil firing on the gas turbine (back up fuel only, < 2 % of operating time)

1. If the solids concentration (soot) in the flue gas is less than 0.2 mg/m^3 (2e-9 ounces per gallon) in dry flue gas corrected to 3 % oxygen, the following shall apply:
 - a. Minimum fin thickness $\geq 1.5 \text{ mm}$ (0.06 in)
 - b. Maximum fin density ≤ 157 fins/m (4 fins/in)
 - c. Maximum fin height $\leq 12.7 \text{ mm}$ (0.5 in)
 - d. No use of serrated fins
 - e. Inline tube alignment is required.
2. For all other applications, the following **shall** apply:
 - a. Minimum fin thickness $\geq 2.5 \text{ mm}$ (0.1 in)
 - b. Maximum fin density ≤ 80 fins/m (2 fins/in)
 - c. Maximum fin height $\leq 19.1 \text{ mm}$ (0.75 in)
 - d. Solid fins only (or bare tubes)
 - e. Inline tube alignment.
 - f. Installation of adequate tube bank cleaning facilities.

2.2.5.3 Superheater

1. The sizing of headers, piping and tubes shall be such that the steam flow is evenly distributed over parallel superheater sections and tubes with a maximum deviation to average of $\pm 5 \%$.
2. For membrane type boilers the superheater headers shall be outside flue gas passage.
3. The maximum number of tube rows (in flue gas direction) per harp (i.e. between same top and bottom header) shall be two.
4. No multiple pass SH harps (i.e. up and down flow in same harp) shall be applied.
5. Only full penetration tube to header connections, using stubs shall be used, i.e., direct tube to header weld is not allowed.
6. The steam velocities in the tubes shall be at least 20 m/s (65 ft/s) at MCR.
7. In HRSGs with average flue gas temperature entering first tube row of more than 700°C (i.e. outlet 'furnace'), superheater tubes shall be shielded by minimum of three (3) rows of evaporator screen tubes.
 - a. When process design will not allow for three (3) rows of evaporator screen (e.g., SH temperatures cannot be reached), use of bare tube SH may be acceptable instead but in such cases the first three SH rows shall be maximum one(1) row per harp.
8. Superheaters shall be designed so that the mechanical stresses resulting from differences in tube wall temperature between tubes are minimised.
 - a. The Supplier shall prove at the Principal's request that material stresses remain below the allowable stresses according to the relevant piping design code (i.e., ASME B31.1) when the full tube wall temperature differences due to radiation, flue gas maldistribution and flue gas temperature differences are taken into account.

- b. The Manufacturer/Supplier shall prove and show by analysis that the thermo-mechanical stresses are low enough to permit a fatigue design life commensurate with the specified lifetime and operating cycles.
9. Adequate cooling of the superheater during start-up and blowing safety valves shall be assured. Refer to (2.6.1).
10. Superheater drains shall be sufficiently sized to allow for complete draining of the SH during purge phase at start-up.

2.2.5.4 Evaporator

1. The maximum local peak heat flux, under any operating condition, shall not exceed 250 kW/m^2 (80000 Btu/h ft^2).
2. Natural circulation vertical tube evaporators should be chosen in preference to forced circulation (horizontal) tubes.
3. Other arrangements such as inclined tubes, horizontal tubes or combined vertical/horizontal tubes may be considered if the minimum circulation ratios and mixture velocities as specified below can be achieved with an elevated location of the steam drum. Such a system shall only be allowed if clear evidence of the successful application of the proposed natural circulation principle in a similar installation (temperature, heat fluxes, flue gas direction and pressures) has been demonstrated by the Supplier to the satisfaction of the Principal.
4. The design of the evaporator and circulation system shall be such that, at all boiler loads, the steam/water two phase mixture will not suffer phase separation (stratified flow or stratified-wavy flow), which causes local dry-out of the internal tube surface and subsequent salt deposition, caustic gouging and/or tube overheating.
5. The circulation ratio (ratio of total circulating mass to MCR steam production) and the applied velocities in the boiler shall as a minimum comply with the graph below for each circulation circuit/Module//tube row:

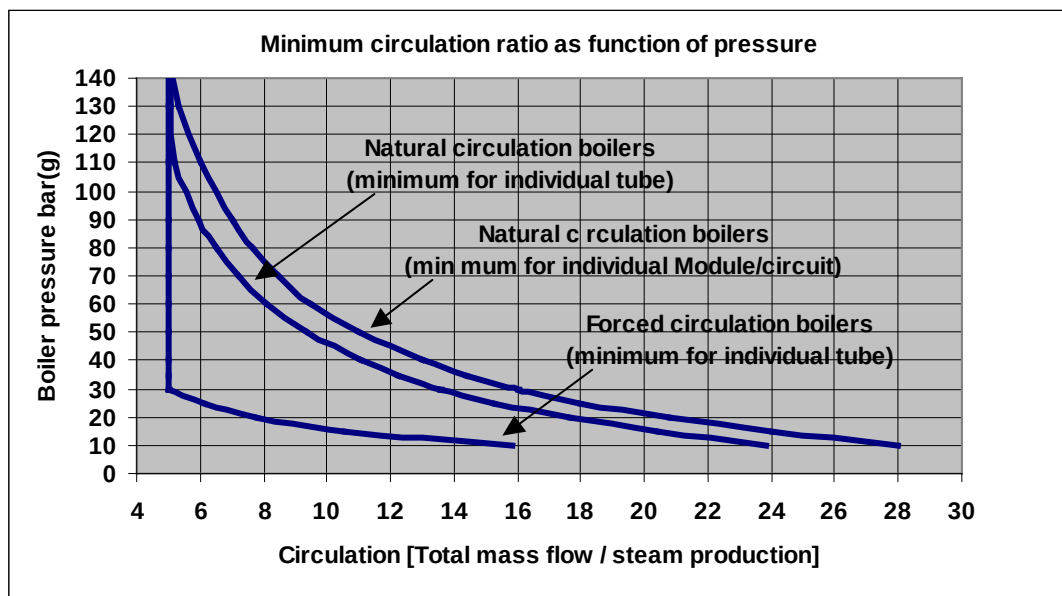


Figure 1 Minimum circulation ratio as function of drum operating pressure

6. , A minimum circulation ratio for tube modules or in individual tubes shall be adhered to.
 - a. For forced circulation boilers: The water velocity at the inlet of each individual pass shall be a minimum of 1.75 m/s (5.7 ft/s) while the mixture outlet velocity

- shall not exceed 25 m/s (80 ft/s) (criteria based on no diameter changes in passes).
- b. For natural circulation horizontal tubes, the water velocity at the inlet of each individual pass shall be at least 1 m/s (3.3 ft/s) (criterion based on no diameter changes in passes).
 - c. The circulation ratio should be at least equal to the minimum requirements set by the Supplier for the proposed design and water quality.
7. For forced circulation boilers, the water circulation and content in the tubes shall remain sufficient to protect the coils:
 - a. During the period between breakdown of one circulation pump and take-over by the spare pump;
 - b. Against the residual heat accumulated in the boiler during a complete power failure.
 8. Alternative approaches, supported by theory and calculations may be applied subject to approval by the Principal.
 9. No multiple pass evaporator harps (i.e. up and down flow in same harp) shall be applied.

2.2.5.5 Economiser

1. All metal surfaces in contact with flue gas shall be at least 15°C (27°F) above the (acid) dew point which may occur during any of the operating cases (excluding start-up), in combination with any of the specified fuels. The dewpoint calculation method shall be in accordance with ISO 13705.
2. The design of the economiser shall be such that there are no steaming conditions during operation.
 - a. Approach points of less than 7°C (13°F) are not allowed unless last pass is fully upwards or other means to prevent steaming, e.g., use of Feedwater control valve downstream economiser, are applied.
 - b. 'Anti-steaming' measures are subject to the Principal's approval and shall be supported by evidence of successful comparable systems.
3. Manufacturer/Supplier shall prove that the economiser design has been thoroughly analysed for downflow stability over the full operating range.
4. When using multiple pass economisers (i.e. up and downflow in same harp) the differential temperature in process inlet and outlet temperature (i.e. differential temperature over internal partition plate) as well as differential metal temperatures shall not exceed 28 °C (50 °F).
5. Economiser design shall be such that FAC is avoided. The maximum velocity in tubes shall be less than 4.0 m/s.

2.3 ROTATING EQUIPMENT

2.3.1 Circulating pumps

1. Boilers with forced circulation shall have two x 100 % duty circulating pumps suitable for unrestricted parallel operation. However one pump shall be suitable to satisfy all operating cases, while the second pump is on standby and is used only in case of failure of the first pump.
2. The margin between net pressure suction head available (NPSHA) and net pressure suction head required (NPSHR) shall take into account reduced NPSHA due to fouled strainers, or when drum operating pressure is dropping rapidly. A margin of at least 3 m (10 ft) shall be maintained.

- 3. Principal shall specify the type of pump drives (e.g., steam turbine, electric motor, other) to be used

2.3.2 Forced-draught fans

- 1. Standby forced draught fans, intended to supply combustion air following a gas turbine trip, shall not be supplied unless specified by the Principal. The Manufacturer/Supplier shall indicate any limitation on the steam output of the boiler during operation with a standby fan (fresh air operation), if this is applied.
- 2. Auxiliary air fans, cooling/purge air fans, ignition burner air supply fans (2.5.3), sealing air fans (2.4.2) and DeNOx system flue gas or air fans shall be provided if required.
- 3. The air intake of the fans shall be at safe location to be approved by the Principal and filtered if required to prevent fouling of downstream equipment or instruments. Provision for changing filter element without need for shutting down the unit shall be provided.

2.4 TURBINE EXHAUST GAS AND FLUE GAS SYSTEM

2.4.1 Gas flow induced vibrations

1. The Manufacturer/Supplier shall include in the design all measures necessary to ensure that no part of the boiler installation and ducting shall be subject to vibrations that may reduce the lifetime of any part of the boiler and ducting, or create equipment noise exceeding the limitations described in (2.9).
2. Frequencies of gas vortex shedding from the tubes shall not excite or resonate with the natural frequencies of the tubes, nor excite or resonate with acoustic frequencies of the boiler casing or ducting.
3. The Manufacturer/Supplier shall provide a report on flow induced vibration covering, vortex shedding, turbulent buffeting and fluid elastic whirling. The analysis report should, as a minimum, contain Strouhal numbers, flue gas vortex shedding frequencies for each tube bank, as well as the lower natural frequencies of the tubes, and the acoustic frequencies of the boiler casing taking into account the presence of tubes.
 - a. If, after initial start-up, it is found that corrective action to reduce vibration is necessary, it shall be the responsibility of the Manufacturer/Supplier to apply corrective measures prior to the hand-over of the boiler to the Principal.
 - b. The corrective measures applied shall be subject to the approval of the Principal.

2.4.2 Firebox observation

1. Air-cooled observation windows shall be provided on auxiliary fired boilers. The observation windows shall provide proper view at flames, walls, etc. in line with the following minimum requirements:
 - a. a 50 % view of the total duct burner plane of a matrix duct burner, with at least 25 % of each individual burner;
 - b. a 100 % view of all burner throats of register type burners;
 - c. a view of all pilot flames;
 - d. a cross-sectional view at the furnace outlet covering the area closest to the burners to verify flame lengths and absence of flame impingement;
 - e. views parallel to all membrane walls at burner elevation to verify the absence of flame impingement on furnace walls.
 - f. A 50 % view of the downstream tubes
 - g. Minimum free view cross section 150 mm x 150 mm (6 in x 6 in)

2. A peephole may be used to view for proof of a pilot flame.
3. The observation windows glasses (as well as peephole glasses) shall be made from fused silica glass as minimum, and protected on the hot side by pivoting metal plates. The glasses, frames and view tubes shall be equipped with air supply for purging and cooling.
4. Air for any of the above purposes shall not be supplied by the instrument/plant air system but by two 100 % duty purge air fans combined with the ignition burner air supply.
 - a. Damper seal air supply (where applicable) shall be supplied from separate sealing air fans.
 - b. Each purge air fan and sealing air fan shall be capable of supplying at least 125 % of the nominal required air for all observation windows, igniters and damper seals in order to reduce the risk of overheating and flue gas leakage.
5. Purge air capacity, supply lines and connections shall be designed to maintain at least 1 m/s (3.3 ft/s) velocity over the internal cross-section of the view tube (regardless of the view hole diameter), or to maintain a pressure in the observation window sleeve of 15 mbar (6 in of water) higher than the highest TEG pressure.
6. The Manufacturer/Supplier shall provide general arrangement drawings of viewports and locations, together with view areas for approval by the Principal.

2.4.3 Flue gas path access

1. There shall be an access door and access space upstream and downstream of each tube bank and ducting separation (burners, dampers or flow straightening devices).
 - a. For access doors in water tube walls, a minimum free opening of 400 mm (16 in) diameter (circular) or 400 mm x 400 mm (16 in x 16 in) (rectangular) is allowed, whereas in other duct walls a rectangular opening of at least 600 mm x 600 mm (24 in x 24 in) is required.
 - b. The minimum distance for access between convective tube banks shall be 700 mm (28 in).

2.4.4 Ducting general

1. The ducting includes all gas turbine exhaust ducts, the HRSG casing, the sections for the auxiliary firing burners, transition sections and expansion joints as far as the stack.
2. The HRSG casing walls shall be constructed of steel plate with minimum thickness of 6 mm (0.25 in).
 - a. The casing shall have a design pressure based on the most severe combination of the wind pressure/suction and 1.5 times the maximum operating pressure in the casing, but not less than 50 mbar (20 in of water).
 - b. If a combined stack outside the Supplier's scope is used, the Principal shall specify the vacuum design pressure (maximum draught), and maximum back pressure.
3. Ducting shall be sufficiently rigid to prevent damage from vibration and avoid drumming when exposed to gas turbine exhaust flow over the complete flow range. Duct sections shall be suitably stiffened to minimize distortion and withstand seismic and wind loads. Effective vibration isolation from the gas turbine is particularly essential.
4. Duct plate shall be designed to limit the deflections to 1/100 of the span of plate between stiffeners, taking full advantage of multispan continuity where appropriate, under design conditions.
5. Duct stiffeners shall be designed to limit deflection to 1/240 of the stiffener or support span under design conditions.

6. All stiffeners shall be provided with weep holes so that rainwater cannot accumulate. Horizontal (flat) sections of casing shall be designed sloping to avoid accumulation of rainwater.
7. Drains with manual block valve shall be provided on ducting and all bottom dead spaces.
8. All heat recovery steam generator (HRSG) casing joints (factory and field joints) shall be welded and gas tight to provide zero leakage. Field joints shall be insulated (staggered) and lined in the field during assembly by means of prefabricated internal liner sheets by the HRSG Supplier.
9. Flanged connections shall not be applied, unless seal welded after installation.
10. Ducting bends shall have rounded profiles and be fitted with guide vanes if required. Guide vanes shall be designed to avoid resonance and the formation of eddies in the turbine exhaust gas (TEG) stream; hence, they shall have a smooth tapered leading edge in line with the flue gas direction.
11. For the ducting design, the average gas velocity shall be limited to a maximum of 30 m/s (100 ft/s). For auxiliary burners, the flue gas velocity shall comply with the burner Supplier's requirements for optimum performance over the entire operating envelope.
12. Transition pieces between duct sections of different cross-sectional areas shall be provided if necessary.
13. Diverging sections shall be designed commensurate with the maintaining of gas flow uniformity across the cross-sectional area.
 - a. They shall be designed with the objective of preventing flow detachment from the duct wall and providing the most economical pressure loss.
 - b. If necessary, guide vanes shall be used to maintain flow uniformity.
- 14. The Principal shall specify in the requisition whether the ducting design shall be flow model tested.
15. Expansion joints shall be provided in the flue gas ducting as necessary. Thermal insulation of flue gas ducting shall be internal (refer to (2.7.5)). Where insulation is for personnel protection only, wire screen barriers are an acceptable alternative.
16. Duct supports shall be designed in order to remove all loads from the boiler casing. Sliding supports shall be designed to allow lateral and axial expansion movements of the ducting.

2.4.5 Boiler inlet ducting

1. The boiler Manufacturer shall be responsible for the design of the interface between gas turbine and boiler, and cooperate closely with the gas turbine Supplier.
2. For auxiliary fired boilers, the design of the inlet ducting shall ensure flue gas flow distribution over the burner and tubes in compliance with the requirements of (2.4.6).

2.4.6 Combustion chamber

2.4.6.1 General

1. For combustion chambers in auxiliary fired HRSGs, two systems are allowed (a. or b.):
 - a. Uncooled combustion chamber with fibre insulation clad with floating metal sheeting,
 - b. Uncooled refractory lined combustion chamber.
2. Cooled combustion chamber (furnace), shall only be used after explicit approval by the Principal and if no other solution can be found.
3. Fibre-based unclad insulation systems shall not be applied.

4. The system to be applied depends on the applicable design temperature. The hot face design temperature and peak flue gas temperature shall be determined as the maximum value for all design cases using the following formula:

$$a. \text{ Hot face design temperature} = T_{\text{TEG}} + (T_{\text{adiabatic}} - T_{\text{TEG}}) \times 1.25 \times 1.2$$

5. TEG shall be replaced with combustion air, if fresh air operation is specified.

Adiabatic firing temperature is defined as the average firing temperature based on given fuel, TEG or air flow, considering no heat loss, complete combustion and perfect mixing.

$$b. \text{ Peak flue gas temperature} = T_{\text{TEG}} + (T_{\text{adiabatic}} - T_{\text{TEG}}) \times 1.25$$

The calculated peak flue gas temperature downstream of the duct burner is the TEG temperature plus the difference between the TEG temperature and the calculated adiabatic flame temperature multiplied by 1.25. The factor 1.25 allows for a minimum flue gas velocity of 20 % below the average at the cross section of the duct burner.

6. The **peak flame temperature**, serving as hot design temperature, shall be calculated as 1.2 times the peak flue gas temperature.
7. The type of combustion chamber and lining shall be selected in accordance with the hot-face design temperatures, as shown in Table 1. The factor of 1.2 is based on the assumption that there is no direct flame contact with the walls, tubes or any other parts in the furnace.

No reduction of the factors in the above hot face design temperature is allowed.

Table 1 Types of HRSG combustion chamber and lining, for virtually sulphur free fuels (<50 ppmV total sulphur, >98 % of time)

Types of combustion chamber and lining	Hot face design temperature	Hot face design temperature
	(continuous operation)	(peak load operation, max. 2 hr in any 24 hr)
Metal clad fibres	< 1035°C (1900°F)	< 1100°C (2010°F)
Refractory lined	< 1260°C (2300°F)	< 1260°C (2300°F)
Water cooled (furnace) walls (no inside insulation)	> 1260°C (2300°F)	> 1260°C (2300°F)

6. If the sulphur content of the gas turbine and auxiliary-firing fuels combined is more than 50 ppmv for more than 2 % of the time, the allowable hot face design temperature for metal clad fibres shall be reduced to a temperature to be agreed with the Principal.

2.4.6.2 Uncooled combustion chamber

- The design of the combustion chamber and boiler inlet duct shall be such that the TEG is evenly distributed across the boiler inlet and burners and so that localised overheating and flame impingement is prevented.
- To prevent flame impingement and to minimize the flue gas temperature gradients downstream of the burner, the flow and temperature distribution shall comply with the following:

- a. the flue gas velocity in 95 % of the cross section just upstream of the burner is within 20 % of the RMS average flue gas velocity;
 - b. flow direction over the complete cross section upstream of the burner shall be within 15° of axis X-X in Figure 2;
 - c. the temperature at the inlet of the first heating surface shall not vary by more than ± 50 °C (90 °F) from the average at any firing condition;
 - d. the maximum velocities at the inlet first heating surface shall be less than 2 x cross section average.
3. Unless alternatives are supported by three-dimensional, computational fluid dynamics (CFD) modelling based on a gas turbine outlet flange profile made available by the gas turbine Manufacturer/Supplier and/ or physical flow model testing, the following requirement shall be adhered to as minimum (see also Figure 2):
 - a. The duct burner frame shall be placed perpendicular with the centreline of the upstream and downstream duct;
 - b. The duct downstream of the duct burners shall diverge symmetrically with the centreline of the upstream duct (β);
 - c. The enclosed angle of the duct upstream of the duct burner shall not be more than 20° ($\alpha \leq 10^\circ$);
 - d. To accommodate changes in direction, each change shall be no greater than 25° (angle Y in Figure 2). The distance between breaks shall be at least the same as the length of the previous section (i.e., L1 shall be at least as long as L in Figure 2);
 - e. The distance, (measured in TEG direction from the burner closest to the first tube row) to the cross section at which the flue temperatures are measured upstream of the first tube row, shall be at least 1.25 times the flame length specified by the burner Supplier with a minimum of at least 4.5 m (15 ft).

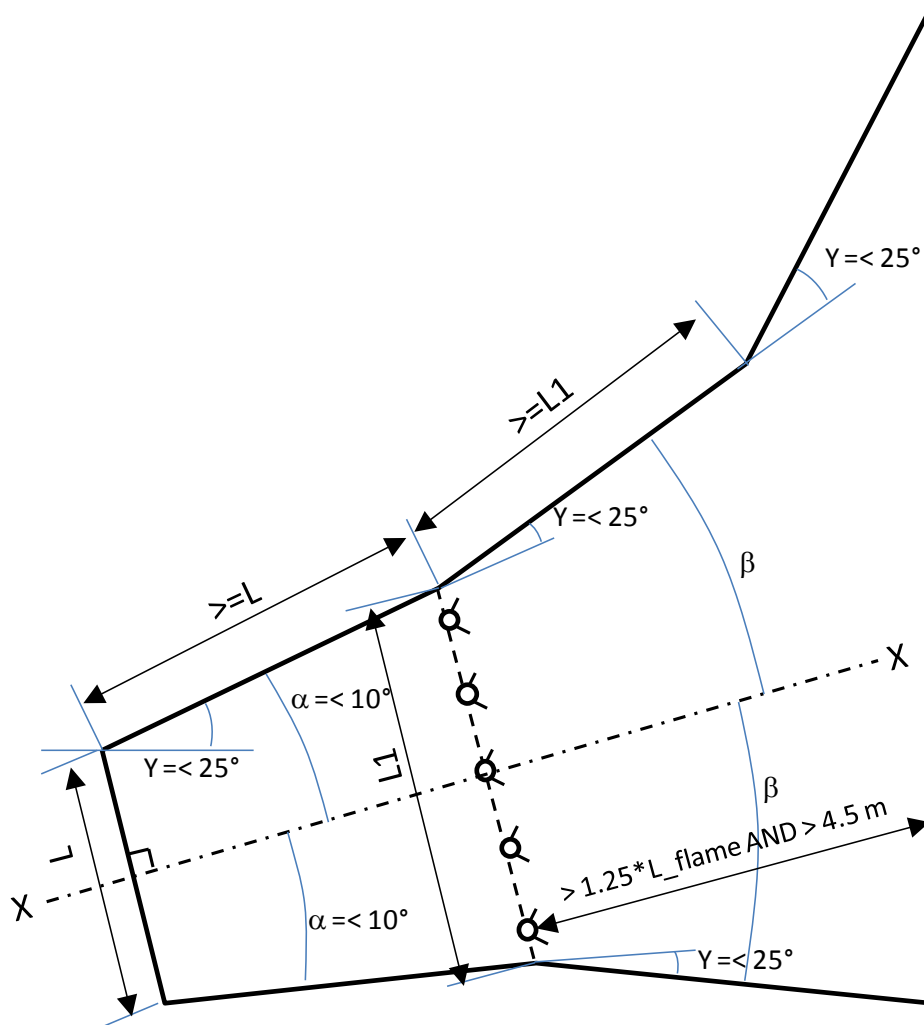


Figure 2 Example of inlet duct and combustion chamber layout

4. The above requirements promote even flue gas distribution but do not ensure either proper distribution or sufficient flow straightening of the highly turbulent TEG gases. Guide vanes, grids or bars may still be required. The requirements for these flow distribution devices shall be determined by the Supplier and are subject to approval by Principal.
5. No adjustment/tuning, either passive or active, shall be applied in the fuel gas supply to individual burners (element/rows) to compensate for TEG flow maldistribution. This includes restriction orifices, different nozzles sizes, reduced drilling, throttle valves, etc.
6. The Manufacturer/Supplier of the HRSG design shall also fulfil the flow/temperature distribution requirements of the duct burner Supplier.

2.4.6.3 Cooled combustion chamber (furnace)

1. A furnace shall consist of membrane wall-type water-cooled gas-tight walls, roof and floor. Any attachments to membrane walls shall be made to the strips between the tubes, not to the tubes themselves.
2. The furnace shall be sized so that the maximum local peak heat flux at any location, under any operating condition, shall not exceed 250 kW/m^2 (80000 Btu/h ft^2), based on the actual tube surface area exposed to the fire side (see definition of cooling surface below).

3. The Manufacturer/Supplier shall state on the requisition the maximum heat released (kW/m^3 ($\text{Btu/h ft}^2 \text{ F}$)) and heat flux (kW/m^2 (Btu/h ft^2)) in the furnace, based on the furnace volume and areas as defined below.
4. For the calculation of the above quantities, the following definitions shall be used:
 - a. The **furnace outlet** is defined as the plane through which the combustion gases leave the furnace as defined by the furnace volume and cooling surface below. Furnace outlet temperature and pressure are defined as the average gas temperature and pressure in this plane.
 - b. The **furnace volume** is that which is enclosed by a geometrical surface comprising the furnace outlet and surfaces laid through the centrelines of those tubes which are exposed to direct radiation, and the surfaces occupied by the burners and refractory.
 - c. The **cooling surface** to be used in the calculation of the average heat transfer rate in the furnace shall be defined as the actual tube surface (i.e., the half tube round surface) exposed to the fire side, which encloses the furnace volume described above.
5. Furnace tubes shall be bent around observation ports, burner ports, etc.
6. No furnace tube shall be bifurcated, as this can lead to unstable flow.
7. Burner lay-out and the path of the flue gas through the furnace shall ensure symmetrical heat flux loading of the furnace walls and all convection banks. The flue gas distribution tolerances provided in (2.4.6.2) for uncooled combustion chambers are also applicable to furnaces.
8. Flames shall not impinge on walls, floor and roof or any metal part during any operating condition.

2.4.7 Flue gas dampers and isolators

2.4.7.1 General

- 1. The Principal shall specify whether dampers or isolators are needed. A damper may be required for one or more of the following reasons:
 - a. Connection of the turbine exhaust to a bypass stack during start-up of the turbine to allow unrestricted gas turbine start-up time;
 - b. TEG flow regulation for boiler start-up or control purposes;
 - c. continued turbine operation during HRSG shutdown;
 - d. thermal isolation of the shut-down boiler during normal turbine operations;
 - e. change-over for auxiliary fired boiler from TEG operation to fresh air fired operation (if applicable)
- 2. Dampers and isolators (if fitted) shall be located upstream of the burners.

2.4.7.2 Bypass dampers

2.4.7.2.1 Types

1. Dampers can either be of the louvre type or diverter type.
 - a. The louvre type shall be used if required to accurately control the TEG flow to the downstream heating surface, e.g., to process coils where equal heat and flow distribution is of eminent importance or to boilers where conservation of steam temperature and pressure are important (i.e., during a controlled or automatic take over from TEG to fresh air operation or vice versa).
 - b. If the louvre system is used, fail safe (mechanical) interlocking shall be applied to ensure an open gas path for TEG.

2. The achieved seal efficiency shall be > 99.5 % for both the HRSG and bypass stack (process considerations only) and 100 % for the HRSG if a safe atmosphere (for entry) in the HRSG casing is required with the gas turbine in operation.

2.4.7.2.2 Sealing system

1. Sealing systems shall feature a double seal.
 - a. The cavity between the seals shall be buffered by seal air fans to maintain a positive isolation.
 - b. The air seal (buffer) system shall be instrumented to detect any seal leak or loss of air supply (in which case a back-up fan can be started).
 - c. The pressure tapping shall be on the seal, downstream of any dampers provided and opposite the seal air inlet connection.
2. The seal air pressure shall be 50 mbar(g) (20 in(g) of water)) or 10 mbar (4 in of water) above the maximum TEG pressure, whichever is higher.
3. The seal air fan capacity shall be at least twice the calculated seal leak rate to cover future deterioration of the seals.
4. Seals shall be all-metal, non-permeable and flexible, so as to accommodate expansion and movements of the damper and casing.
 - a. The sealing function shall not deteriorate under the influence of high flue gas temperature and high flue gas velocity (e.g., when dampers reach end position close or open). Their sealing efficiency shall be assisted by the pressure difference across the blade.
 - b. The Manufacturer/Supplier shall state on the requisition the degree of gas flow isolation, as a percentage of TEG flow at maximum load, provided by the damper type proposed.

2.4.7.2.3 Blades, shaft and operating gear

1. The shaft(s), blade(s) and seals shall be of robust construction and shall be designed to prevent vibration or fluttering at any blade position under any operating condition.
2. Damper components shall not be subject to distortion or deterioration due to corrosive, high temperature or velocity conditions and not move under the effects of gravity, dynamic pressure or vibration.
3. The damper operating gear shall be outside of the ducting, so as to be accessible for inspection and maintenance during normal boiler operations.
4. The damper shaft shall extend through the duct wall to external bearings and sealed to prevent gas leakage. The shaft seals may be a labyrinth of metal diaphragms to accommodate expansion.
5. The damper shaft bearings shall be of the self-aligning and non-lubrication type.
 - a. Materials shall be non-jamming (bronze) and can consist of replaceable pads.
 - b. The design shall ensure that the shaft at the bearing area is adequately cooled. The maximum allowable operating temperature of the bearing shall be well below the temperature as specified by the bearing Supplier.
 - c. Levers shall be attached to shafts by means of sunk keys or rectangular ends. The shaft shall be marked to indicate the blade position.
6. The TEG design temperature of the damper module shall be 50°C (90°F) higher than the highest TEG temperature specified on the requisition.
7. Damper shaft drives may be electric motor or pneumatic. Hydraulic actuators are subject to the approval of the Principal.
8. In auxiliary fired HRSGs with fresh air operation, the transition time for the TEG/air change-over damper shall be one of the following:

- a. less than 10 s for GTs <75 MW;
 - b. less than 20 s for GT's >75 MW.
9. Actuators shall be capable of developing at least 110 % of the force required by the damper under the most severe operating condition.
10. The equipment for manual operation shall be easily accessible.
 - a. A shaft-mounted position indicator shall be included which is clearly visible during manual operation, and from grade level.
 - b. Damper shaft drives shall be capable of transmitting at least 110 % of the maximum motor torque. A disengaging clutch shall be incorporated to facilitate manual operation of the damper.
 - c. Couplings in the transmission shaft(s) shall be all-metal and flexible.
11. The maximum blade travel in both directions shall be controlled by limit switches.
 - a. The mounting brackets of the limit switches shall be adjustable so as to allow the closing positions of the damper blade to be set accurately.
 - b. Unless specified otherwise, limit switches shall be contact free, rigid and robust.
 - c. Location and orientation of limit switches shall not be effected by thermal expansion of the blade and the shaft.
12. Thermal insulation of the damper module shall comply with (2.1) and (2.7.5) and be an integrated part of the lining design with no hot spots at module connections.

2.4.7.3 Spade plate isolators

- 1. The Principal shall specify whether a spade blade isolator is required and what type to use, and if the space blade isolator is provided in an open atmosphere or inside a fully closed cover.
 2. Spade plate isolators may be applied if 100 % gas tightness is required.
 3. The spade plate shall be inserted into the ducting joint downstream of the damper. The spade plate shall be thick enough and sufficiently stiffened to avoid distortion, and to withstand at least 1.5 times the bursting pressure of the ducting.
 4. The TEG design temperature of the spade plate isolator shall be 50°C (90°F) higher than the highest TEG temperature specified on the requisition.
 5. Unless otherwise specified, spade plates shall be designed in stainless steel.
 6. The spade plate shall be inserted from the top of the ducting by means of an electrical driving mechanism, e.g., via a main shaft and a two-sided installed chain and wheel mechanism pulling the spade into the seals. The spade shall be secured and stored in an enclosure installed above the duct while not in use.
 7. The slot in the duct to insert the spade during use shall be sealed with a flange and designed so that thermal insulation and purge is sufficient to avoid overheating and hot spots. The maximum allowable temperature during normal operation shall be in line with the requirements of (2.7.5).
 8. In order to enable safe working conditions in the HRSG/WHRU while the GT is in operation, a seal air connection is required as shown in Figure D.3. Alternatively, a seal air connection on the spade blade isolator sealing chamber may be provided.

2.4.8 Stacks

1. The HRSG shall have its own stack and, where specified, a boiler bypass stack. Stacks shall be in accordance with DEP 34.24.26.31-Gen. If the stacks are excluded from the scope of supply, the boiler Manufacturer/Supplier shall provide the necessary information to enable the Principal to design them.

- - 2. Bypass stacks shall be provided with a "top hat" or other suitable provision to prevent the ingress of rain. Principal shall specify whether a top hat shall be supplied.
 - 3. As a minimum, the stack shall be provided with one DN 150 (6 in) and four DN 80 (3 in) emission sampling test ports (stainless steel) with blind flange bolted covers with chains.
 - a. Blind flanges shall be fitted with a threaded cap to allow flue gas spot measurements.
 - b. The blind flange and bolting material shall be the same as the sample port material.
 - 4. As a minimum, the stack shall be provided with personnel protection in areas where personnel access may be required during operation and testing, i.e., ladders, platforms and base. In case of acid dew point issues, the stack shall be insulated to keep the stack metal temperature above the acid dew point.
- - 5. A continuous emission monitoring system (CEMS) shall be supplied, if specified by the Principal.
- - 6. The minimum stack height shall be as specified by the Principal.

2.4.9 Expansion joints and bellows

- 1. Fabric type or stainless steel bellows may be used. The expansion joints and bellows shall be designed for all the possible movement (compression, tension, torsion, etc.), vibration, etc. of duct and interfacing equipment while maintaining gas tight integrity.
- 2. Steel type bellows shall be equipped with a shield to prevent rain, cooling for the bellow or to protect the bellow for mechanical damage.
- 3. Fabric type bellows or expansion joint(s) shall be a flexible multiple layer type using up-to-date technology and materials suitable for both internal and external environment with a proven record of successful application in gas turbine systems.
- 4. 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. 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.

2.5 AUXILIARY FIRING SYSTEM

2.5.1 General

- - 1. The Principal shall state whether the boiler is to be equipped with auxiliary firing.
 - 2. The auxiliary firing system shall be of a grid/matrix type.

The burner elements (runners) typically are in-line horizontally installed "duct" burners, and are used to increase the duty of the WHRU by increasing the temperature of the TEG.
 - 3. The firing system shall be designed for gaseous fuel only.
 - 4. The fuel properties, including the full range when variable, shall be specified by the Principal.
 - 5. The Manufacturer/Supplier shall design the system to achieve the required boiler performance and allow for safe start-up, normal operation and shut-down with any of the specified fuel compositions.
 - 6. Principal and Supplier shall consider the minimum requirements (e.g., flammability of waste gas) as defined in DEP 20.05.60.10-Gen. Special requirements are applicable in