DEP SPECIFICATION

GAS TURBINE HEAT RECOVERY STEAM GENERATORS

DEP 30.75.10.31-Gen.

February 2012

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 like 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 DEP is a revision of the DEP of the same number dated June 2007. This revision has been extensive. A summary of the main changes is given in (1.5).

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

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

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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 shall be reported back to the Principal throughout the project and are subject to approval by the Principal.

1.3.2 Specific definitions

Term	Definition
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.
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).
Fuel	All fuel gases specified by the Principal for firing in the boiler
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)
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
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)
Supplementary Firing	Firing of fuel in the TEG to supplement the heat input to the boiler (see auxiliary firing)
TEG	Turbine Exhaust Gas

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1.4 CROSS-REFERENCES

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

1.5 SUMMARY OF MAIN CHANGES

The previous edition of this DEP was dated June 2007. Compared to the previous edition, this document has been extensively revised and it is impractical to list all the changes here. The most significant changes are:

- Addition of mandatory requirements to mitigate process safety risks in accordance with Design Engineering Manual DEM 1
- Addition of Control and Safeguarding requirements (coming from DEP 32.24.20.42-Gen., which has now been withdrawn).
- Addition of Amendments/Supplements to NFPA 85 (2011 edition), Chapter 8.

1.6 COMMENTS ON THIS DEP

Comments on this DEP may be sent to the Administrator at standards@shell.com, using the DEP Feedback Form. The DEP Feedback Form can be found on the main page of "DEPs on the Web", available through the Global Technical Standards web portal http://sww.shell.com/standards and on the main page of the DEPs DVD-ROM.

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.

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2. DESIGN AND ENGINEERING

2.1 GENERAL

The boiler shall be of the water-tube type and be suitable for continuous operation in conjunction with a single gas turbine. The boiler shall be suitable for outdoor operation.

The design shall be proven in practice, robust, reliable, safe and easy to operate.

The design shall be based upon largest possible factory built modules with as much equipment as practicable factory assembled.

In an auxiliary fired boiler, the MCR and peak load of the boiler shall be achieved over the turbine load range and duct burner load specified by the Principal on the requisition.

In a boiler which is not equipped with auxiliary firing, the MCR is specified at the maximum continuous site load of the turbine. In such a case, the peak, base and minimum loads of the turbine are specified on the requisition.

The HRSG shall be capable of reaching the final steam temperature over the load range (of gas turbine and HRSG) as specified on the requisition.

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.

The applicable local regulations shall be stated by the Manufacturer/Supplier on the requisition.

The Manufacturer/Supplier shall only utilise standard materials according to internationally recognised material codes for the construction materials and shall clearly indicate which materials are utilised in which boiler section.

If there is danger of freezing during the operation or drainage of any part, including drains of silencers, protection against such freezing shall be provided.

Energy conservation shall be optimised and the emission of pollutants to the environment shall be minimised.

Design, selection of equipment and materials and corrosion protection shall be based on a operative lifetime of 25 years.

2.2 MAJOR PRESSURE PARTS

2.2.1 General

- 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.

External power piping shall be in accordance with the standards specified by the boiler code.

The Manufacturer shall obtain all code stamps and certificates required by local regulations. Stamping in accordance with e.g., ASME I PG-105 is not required unless specified in the applicable regulations. However, the design, construction, inspection, etc. shall be in compliance with the specified boiler code. The Manufacturer's own stamping of boiler in accordance with e.g., ASME I PG-106 shall be deemed adequate.

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

The steam drum shall be entirely outside the flue gas passage.

Drum internals shall be accessible and cleanable, and they shall be fully bolted and removable without damaging the drum. Tube stubs, suitably prepared for welding, shall be provided at the drums if tubes are to be welded at site.

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Nozzles, stub ends for valves, fittings, mountings, tubes and anything to which drum internals, etc., are to be secured shall be shop-welded into place.

The length of the stubs shall be such that welding the tubes to the stubs will have no adverse effects on the drum or stub-to-drum connections.

The size of the drum is to be determined by the following requirements:

- A level difference of at least 150 mm [6 in] between NWL and LWL and 150 mm [6 in] between NWL and HWL.
- At MCR capacity, with continuous blow down at its normal value, and no feedwater intake, a hold-up time of at least 60 s between LWL and LLWL.
- At no steam flow, with feedwater intake at MCR capacity, a response time of at least 30 s between HWL and flooded drum internals (HHWL if installed).

The NWL, LLWL and HHWL shall be indicated by engraved marks on nameplates permanently attached both on the drum(s) and on the level gauges. The supply of feedwater to the drum and the separation of steam and water shall be effected evenly over the length of the drum.

The steam drum shall have factory installed steam separators of sufficient capacity to achieve the required steam quality as reflected in the table below:

Pressure (Drum)		**Required Efficiency**	
[psi]	**[bar]**	**[%]**	**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

The drum(s) shall be accessible from both sides via elliptical manholes (minimum size 490 mm × 390 mm [19 in x 15 in]). The manhole shall open to inside and covers shall be supported by hinches/davits.

Drum manhole covers shall open to inside to prevent potential leakage during operation.

Drum manhole covers shall be elliptic to remove them from the drum.

2.2.3 Downcomers

Downcomers shall be equipped with sufficient means to avoid vortexes in drum level surface and vapour entrainment in the downcomer. Components installed to avoid vortexes and vapour entrainment could be vortex breakers or cover plates located at the inlet of the downcomer.

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Heated downcomers are acceptable only if they are placed in low heat flux zones and circulation is sufficient to avoid steaming in the downcomer under all conditions including rapid pressure changes in the evaporator. To ensure this, the downcomer shall remain free of vapour in steady state conditions at 3 times the calculated maximum heat flux.

Bottom distribution headers shall be equipped with welded nozzles to allow inspection of these headers and of the water distribution piping to individual tube headers. The diameter of the nozzles shall be NPS 2 (DN 50) minimum and provided with welded caps.

2.2.4 De-superheater

If the temperature variations of the superheated steam exceed the limits indicated by the Principal on the requisition, steam temperature control shall be accomplished by desuperheating, using spray water injection. 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.

In order to ensure complete evaporation of the spray water, the steam temperature after desuperheating shall be maintained at a minimum of 25°C [45°F] above the steam saturation temperature for any operating case.

The steam temperature downstream of the desuperheater station shall be confirmed to be dry and superheated by a temperature indicator reading above saturation temperature before entering a next superheater section (see Standard Drawings S 24.010 and S 75.004). The Supplier shall comply with the instructions of the desuperheater Supplier with respect to the minimum straight distance upstream and downstream of the desuperheater.

The thermal design of the boiler shall be balanced so that the total injection water flow shall not exceed 15 % of superheater steam supply to the steam header, provided the injection water quality complies with the water specification as described in EN 12952-12.

2.2.5 Heating surfaces

2.2.5.1 General

In properly designed HRSGs, tube failures are a rare occurrence. Nevertheless, tube repair or plugging shall be addressed in the design. To facilitate the repair and identification of failed tubes, tube banks shall not consist of more than 10 tube rows if there is a screen evaporator, superheater or economiser. For evaporators not directly exposed to the maximum flue gas temperature, this may be increased to 15 tube rows.

NOTE: If the design allows for a different repair method than having to cut healthy tubes to reach a failed tube, then the above requirements may be ignored if the Principal agrees.

The design of the tube banks and casing shall be such that the possibility of flue gas bypassing the coils during start up as well as during normal operation is minimised. Therefore, the free space between the casing wall 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. If necessary, e.g., if a triangular tube pitch is used, strips, baffles or corbels shall be applied to reduce the flow gap.

Reduced drillings may be applied after approval by Principal. The reduced drillings shall be minimum 90% of the related Inner Tube Diameter. Restriction orifices shall not be applied.

Individual tubes shall be supported and guided in a satisfactory manner so as to prevent distortion (lateral movement of more than 1.5 × tube diameter) and damage due to vibration of the tubes.

Tube bank coils shall be supported by a steel structure and shall not rest on internal insulation or cladding. Unless otherwise accepted by the Principal, coil banks shall be top supported and downward expanding.

The coils shall be designed so that no significant mechanical forces due to thermal expansion of the tubes or their supports will occur. No coil constructions subject to stresses due to differences in thermal expansions (like multiple superheater tube rows exposed to different heat fluxes fixed between the same top and bottom header), or meandering flow

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patterns (downward and upward flow between the same top and bottom header with baffles in headers) are allowed unless neither the difference between process inlet and outlet temperatures nor the maximum metal temperature difference in the module exceeds 28°C [50F].

Cross-over piping shall be inside the boiler casing and shall be of the same material and design temperature/pressure as the next header (in the steam/water flow direction). The number of casing protrusions shall be minimised.

Tube-to-header welds, butt-welded tubes or 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.

A straight tube or pipe in a tube bundle shall not be composed of two buttwelded parts, unless approved by the Principal.

An allowance for internal tube fouling shall be included in the design temperatures. The following fouling factors shall be applied to determine operating metal temperatures:

Economiser	4000 W/m^2.K [705 Btu/h ft^2 F]
Evaporator	5880 W/m^2.K [1035 Btu/h ft^2 F]
Superheater	11760 W/m^2.K [2070 Btu/h ft^2 F]

These fouling factors do not need to be included in the thermal rating for the boiler. The responsibility for including sufficient fouling factors to achieve the guaranteed performance is left to the Supplier.

2.2.5.2 Fin density and height

The maximum fin density, fin type and tube alignment depends on the type of fuel to be fired:

Clean gas:

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:

1. The minimum acceptable fin thickness is 1.25 mm [0.05 in].
2. The maximum fin density shall not exceed 236 fins per metre [6 fins per in] and the height shall be maximum 25.4 mm [1 in].
3. Serrated (twisted) fins are acceptable.
4. Staggered tube alignment is allowed.

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

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:

- The maximum fin density shall be 157 fins per metre [4 fins per in]; the minimum fin thickness shall be 1.5 mm [0.06 in] and the maximum fin height shall be 12.7 mm [0.5 in].
- Fins shall be solid.
- Inline tube alignment is required.

All other applications:

- The maximum fin density shall be 80 fins per metre [2 fins per in]; the minimum fin thickness shall be 2.5 mm [0.1 in] and the maximum fin height shall be 19.1 mm [0.75 in].

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- Fins shall be solid.
- Inline tube alignment is required.
- Installation of adequate tube bank cleaning facilities.

2.2.5.3 Superheater

The superheater shall have a substantially flat temperature-load characteristic, so that excessive desuperheating will not be necessary (see (2.2.4) for limits). If a membrane-type wall furnace is applied, superheater headers shall be outside the flue gas passage.

The steam flow shall be evenly distributed across parallel coils of the superheater(s) at all loads (i.e., no coil shall have a flow rate that is more than 5 % different from the average flow rate). The pressure drop over the parallel superheater passes, compared to dynamic flow effects in the headers, shall be such that flow maldistribution is minimised.

The steam velocities in the tubes shall be at least 20 m/s [65 ft/s] at MCR, and the number of tube rows (in the flue gas direction) between the same top and bottom header shall be not more than 2.

If the superheater is subject to radiation (every HRSG with a flue gas temperature entering the first tube row above 700°C [1300°F]) the superheater shall be typically shielded by 3 rows of screen evaporator tubes. If this is not possible for performance reasons (for instance the specified steam temperature cannot be obtained in an unfired HRSG) the first 3 rows in the superheater shall be bare and only contain 1 tube row between the same top and bottom header.

Superheaters shall be designed so that the mechanical stresses resulting from differences in tube wall temperature between tubes are minimised. If the proposed design may suffer mechanical stresses, 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. The Manufacturer/Supplier shall prove that the thermo-mechanical stresses are low enough to permit a fatigue design life commensurate with the operative life of 25 years. The number of cold start-ups shall be assumed to be at least 25 per year. Major operational stress cycles shall be identified by the Manufacturer/Supplier/Principal and taken into account. Fatigue stresses shall be determined by an appropriate method such as a pipe stress analysis program corrected for the presence of weld profiles, or a detailed numerical stress analysis.

Drainable superheaters shall be selected. Only if there is a process or mechanical reason for a non-drainable superheater (e.g., a water cooled furnace, continued in the superheater section), can non-drainable superheaters be accepted, provided that the envisaged sum of cold and warm starts and stops (including trips) of the HRSG is less than 10 per year.

In that case, the start-up procedure shall include provisions for gradual start-up, to allow for evaporation of accumulated water in the superheater tubes. The selection of a non-drainable superheater shall be subject to approval by the Principal.

Arrangements shall be made and instructions shall be given to ensure adequate cooling of the superheater during start-up and safety relief. Refer to (2.6.1).

2.2.5.4 Evaporator

The maximum local peak heat flux, under any operating condition, shall nowhere exceed 250 kW/m^2 [80000 Btu/h ft^2].

Natural circulation vertical tube evaporators are preferred to forced circulation (horizontal) tubes. Other arrangements such as inclined tubes, horizontal tubes or combined vertical/horizontal tubes can 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 should 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) can be satisfactorily demonstrated by the Supplier.

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The mixture velocity and circulation ratio shall be such that, at all boiler loads, the steam/water two phase mixture will not suffer phase separation (stratified or stratified-wavy flow), which causes local dry-out of the internal tube surface and subsequent salt deposition, caustic gouging and/or tube overheating.

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:

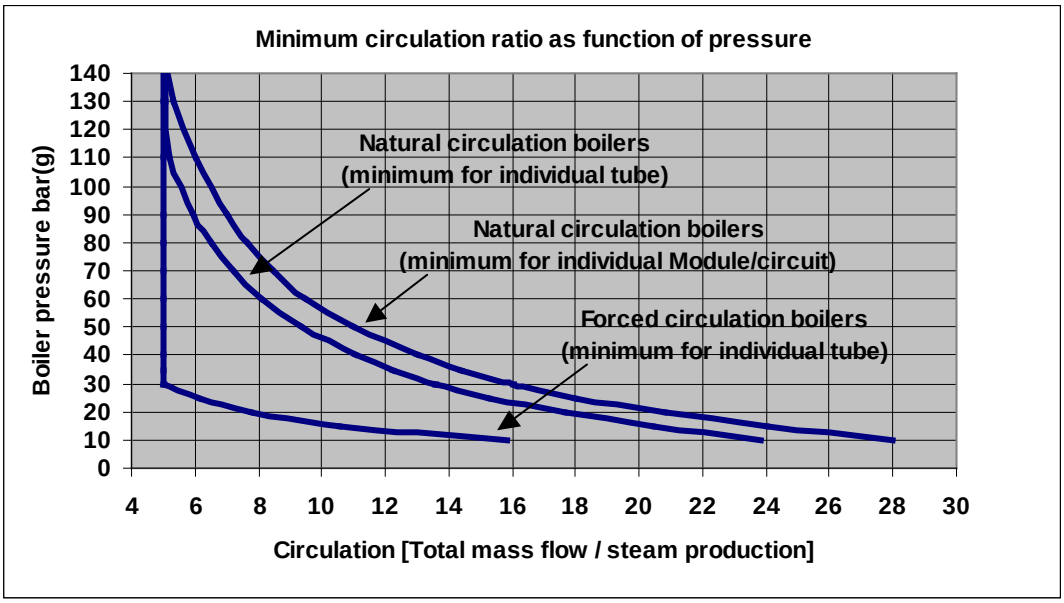

Figure 1 Minimum circulation ratio as function of drum operating pressure

Depending on the level of detail of the Manufacturer/Supplier's circulation study, a minimum circulation ratio for tube modules or in individual tubes shall be adhered to.

1. For forced circulation boilers: The water velocity at the inlet of each individual pass shall be minimum 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).
2. 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).
3. The circulation ratio should be at least equal to the minimum requirements set by the Supplier for the proposed design and water quality.

For forced circulation boilers, the water circulation and content in the tubes shall remain sufficient to protect the coils:

1. During the period between breakdown of one circulation pump and take-over by the spare pump;
2. Against the residual heat accumulated in the boiler during a complete power failure.

Alternative approaches, supported by theory and calculations may be applied subject to Principal approval.

2.2.5.5 Economiser

In the event sulphur containing fuels are fired, all metal surfaces in contact with flue gas shall be at a temperature at least 15°C [27°F] above the highest dew point (acid or water as the case may be) which may occur during any of the operating conditions (excluding start-up) in combination with any of the fuels specified in the requisition. The dewpoint calculation method shall be in accordance with ISO 13705. For fuels with very low sulphur

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content (below 20 ppm), the acid dewpoint can be neglected. In that case the economiser inlet temperature shall remain above the water dewpoint.

The economiser shall not generate steam, as this may lead to stagnant conditions in downwards flowing tubes across the parallel coils (vapour locks). Taking into account flue gas and water maldistribution, the economiser is deemed to potentially generate steam during upsets and transitions if any of the design cases has a water temperature within 7°C [13°F] of the saturation point.

Neither steaming nor an approach point of less than 7°C [13°F] is permitted unless there is entirely upwards flow in the last economiser coil section. Another option is to apply 'anti-steaming' features like a feedwater control valve downstream of the economiser. 'Anti-steaming' measures are subject to the Principal's approval and shall be supported by evidence of successful comparable systems.

The acceptable level of steaming and the mixture flow velocities shall be in line with the requirements for evaporators.

In this case, the steaming economiser shall be connected to the drum as if it were an evaporator riser to avoid any interference with drum level measurement and steam purity.

2.3 ROTATING EQUIPMENT

2.3.1 Circulating pumps

Boilers with forced circulation shall have two 100 % duty circulating pumps, suitable for unrestricted parallel operation.

One pump shall satisfy all requirements. The second pump shall be used only upon failure of the first pump.

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.

Unless specified otherwise by the Principal, to cope with power failures the normally operating pump shall be steam turbine driven and the standby pump shall be electric motor driven. Consequently, the steam turbine does not require auto cut in facilities.

2.3.2 Forced-draught fans

- 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, if this is applied.

Auxiliary air fans, purge air fans, ignition burner air supply fans (2.5.3) and sealing air fans (2.4.2) shall be provided if required.

2.4 TURBINE EXHAUST GAS AND FLUE GAS SYSTEM

2.4.1 Gas flow induced vibrations

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).

Frequencies of gas vortex shedding from the tubes shall not excite or resonate with the natural frequencies of the tubes.

In addition, such vortex shedding frequencies shall not excite or resonate with the acoustic frequencies of the boiler casing or ducting.

The Manufacturer/Supplier shall provide a vibration analysis report showing Strouhal numbers, and the gas vortex shedding frequencies for each tube bank, as well as the lower

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natural frequencies of the tubes, and the acoustic frequencies of the boiler casing taking into account the presence of tubes. 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. However, the corrective measures applied shall be subject to the approval of the Principal.

2.4.2 Firebox observation

Air-cooled observation windows and peepholes shall be provided on auxiliary fired boilers and shall afford a view of burners, flames and surfaces liable to flame impingement. The observation windows/peepholes shall provide at least:

1. a 50 % view of the total duct burner plane of a matrix duct burner, with at least 25 % of each individual burner;
2. a 100 % view of all burner throats of register type burners;
3. a view of all pilot flames;
4. a cross-sectional view at the furnace outlet covering the area closest to the burners to verify flame lengths and absence of flame impingement;
5. views parallel to all membrane walls at burner elevation to verify the absence of flame impingement on furnace walls.

The glasses shall be 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.

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. Damper seal air supply (where applicable) shall be supplied from separate sealing air fans. 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, ignitors and damper seals in order to reduce the risk of overheating and flue gas leakage.

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 inches of water] higher than the highest TEG pressure.

2.4.3 Flue gas path access

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). 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. The minimum distance for access between convective tube banks shall be 700 mm [28 in].

2.4.4 Ducting general

The ducting includes all gas turbine exhaust ducts, the HRSG casing, the sections for the auxiliary firing burners, and the ducts, transition sections and expansion joints as far as the stack.

The HRSG casing walls shall be constructed of steel plate, 6 mm minimum thickness [0.25 in]. 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 inches of water]. 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.

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.

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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.

Duct stiffeners shall be designed to limit deflection to 1/240 of the stiffener or support span under design conditions.

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.

It shall be possible to drain all ducting and bottom dead spaces.

All HRSG casing joints (factory and field joints) shall be gas tight to provide zero leakage. All casing joints shall be welded. Field joints shall be insulated and lagged in the field during assembly by means of prefabricated internal liner sheets by the HRSG Supplier.

Flanged connections shall not be applied, unless seal welded after installation.

The ducting shall be gas tight and smooth, and 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 TEG stream; hence, they shall have a smooth tapered leading edge in line with the flue gas direction.

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.

Transition pieces between duct sections of different cross-sectional areas shall be provided if necessary.

Diverging sections shall be designed commensurate with the maintaining of gas flow uniformity across the cross-sectional area. They shall be designed with the objective of preventing flow detachment from the duct wall and providing the most economical pressure loss. If necessary, guide vanes shall be used to maintain flow uniformity.

- The Principal shall specify in the requisition whether the ducting design shall be flow model tested.

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.

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

The boiler Manufacturer shall be responsible for the design of the interface between gas turbine and boiler, and shall cooperate closely with the gas turbine Supplier.

For auxiliary fired boilers, the design of the inlet ducting shall ensure flue gas flow distribution over the burner complies with the requirements of (2.4.6).

2.4.6 Combustion chamber

2.4.6.1 General

For combustion chambers in auxiliary fired HRSGs, three systems are allowed:

1. Uncooled combustion chamber with fibre insulation clad with floating metal sheeting,
2. Uncooled refractory lined combustion chamber,
3. Cooled combustion chamber (furnace).

Fibre-based unclad insulation systems shall not be applied.

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

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

NOTE: TEG shall be replaced with combustion air if fresh air operation is specified.

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. A lower gas velocity distribution factor may be accepted only if this is supported by 3 dimensional CFD flue gas flow modelling of the whole section from gas turbine exhaust to duct burners, based on the gas turbine exhaust gas plenum data (direction and velocity) supplied by the gas turbine Supplier.

Unless a lower peak flame temperature is supported by proof from the duct burner Manufacturer, the **peak flame temperature** serving as hot face design temperature shall be calculated as 1.2 times the peak flue gas temperature.

The factor 1.2 is low compared to real peak flame temperatures and takes into account that the hottest flame zones will not touch the furnace walls. No reduction shall be factored in for TEG gas intentionally by-passing the duct burner to create a cold buffer between the peak flame temperatures and casing (this is a standard feature accounted for in this factor). The type of combustion chamber and lining shall be selected in accordance with the hot-face design temperatures, as shown in Table 1.

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

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 by 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 so that localised overheating cannot occur and flame impingement is avoided.

To avoid flame impingement and to minimize the flue gas temperature gradients downstream of the burner, the flue gas velocity in 95 % of the burner cross-section shall be within 20 % of the RMS average flue gas velocity. The flue gas direction shall be within 15° of axis X-X in Figure 2.

Unless alternatives are supported by 3 dimensional CFD modeling, based on a gas turbine outlet flange profile made available by the gas turbine Manufacturer/Supplier, or physical

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cold flow model test, the following guidelines shall be adhered to as minimum requirements (see also Figure 2):

1. The duct burner frame shall be placed perpendicular with the centreline of the upstream and downstream duct;
2. The duct downstream of the duct burners shall diverge symmetrically with the centreline of the upstream duct (β);
3. The enclosed angle of the duct upstream of the duct burner shall not be more than 20° (α =< 10°);
4. 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);
5. The distance,(measured in TEG direction from the burner closest to the first tube row) to the first tube row, shall be at least 1.25 times the flame length specified by the burner Supplier, but in any case shall be at least 4.5 m [15 ft].

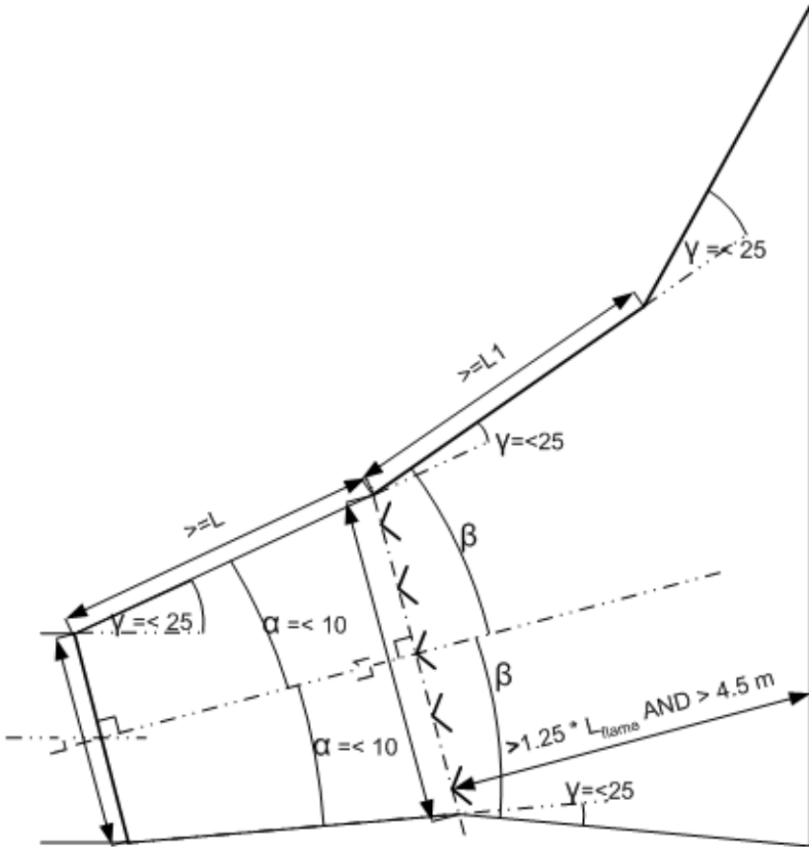

Figure 2 Example of inlet duct and combustion chamber layout

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.

Restriction orifices shall not be applied in the fuel gas supply to individual burners to compensate for TEG flow maldistribution, and neither shall nozzles of different sizes be drilled between individual burner rows.

The minimum requirements specified by the duct burner Supplier to guarantee performance and emission levels shall prevail in the design of the combustion chamber and transition

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duct. The Supplier of the burner shall specify the requirements and it is the responsibility of the HRSG Supplier to fulfil these.

2.4.6.3 Cooled combustion chamber (furnace)

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.

The furnace shall be sized so that the maximum local peak heat flux, under any operating condition, shall nowhere exceed 250 kW/m^2 [80000 Btu/h ft2], based on the actual tube surface area exposed to the fire side (see definition of cooling surface below).

The Manufacturer/Supplier shall state on the requisition the maximum heat released (kW/m^3 [Btu/h ft^2 F]) and heat flux (kW/m^2 [Btu/h ft^2]) in the furnace, based on the furnace volume and areas as defined below.

For the calculation of the above quantities, the following definitions shall be used:

- 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.
- 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.
- 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.

Furnace tubes shall be bent around observation ports, burner ports, etc.

No furnace tube shall be bifurcated, as this can lead to unstable flow.

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 applicable to furnaces too.

Flames shall not impinge on walls, floor and roof or any metal part during any operating condition.

2.4.7 Dampers and isolators

2.4.7.1 General

The Principal shall indicate whether dampers are needed. Dampers can be required if one or more of the following functions are required:

1. connection of the turbine exhaust to a bypass stack during start-up of the turbine to allow unrestricted gas turbine start-up time;
2. TEG flow regulation for boiler start-up or control purposes;
3. continued turbine operation during HRSG shutdown;
4. thermal isolation of the shut-down boiler during normal turbine operations;
5. change-over of auxiliary fired boiler from TEG to auxiliary air (if applicable).

Dampers and isolators (if fitted) shall be located upstream of the burners.

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2.4.7.2 Bypass dampers

Types:

Dampers can either be of the louvre type or diverter type. 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). If the louvre system is used, fail safe (mechanical) interlocking shall be applied to ensure an open gas-path for TEG.

- The Principal shall specify whether the damper system shall provide a safe atmosphere (for entry) downstream of the damper(s) or not.

The achieved seal efficiency shall be at > 99.5 % for both the HRSG and by-pass stack (process considerations only) and 100 % for the HRSG if a safe atmosphere (for entry) in the HRSG casing is to be created with the gas turbine running.

Sealing system:

Sealing systems shall feature a double seal. The cavity between the seals shall be buffered by auxiliary fans to maintain a positive isolation. The air 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). The pressure tapping shall be on the seal, downstream of any dampers provided and opposite the seal air inlet connection.

The seal air pressure shall be 50 mbar (ga) [20 inches of water (ga)] or 10 mbar [4 inches of water] above the maximum TEG pressure, whichever is higher.

The seal air fan capacity shall be at least twice the calculated seal leak rate to cover future deterioration of the seals.

Seals shall be all-metal, non-permeable and flexible, so as to accommodate expansion and movements of the damper and casing. The sealing function shall not deteriorate under 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. 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.

Blades, shaft and operating gear:

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.

Damper components shall not be subject to distortion or deterioration due to corrosive, high temperature or velocity conditions. The damper blade shall not move under the effects of gravity, dynamic pressure or vibration.

The damper operating gear shall be outside of the ducting, so as to be accessible for inspection and maintenance during normal boiler operations.

The damper shaft shall extend through the duct wall to external bearings and shall be sealed to prevent gas leakage. The shaft seals can be a labyrinth of metal diaphragms to accommodate expansion.

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. 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. Levers shall be attached to shafts by means of sunk keys or rectangular ends. The shaft shall be marked to indicate the blade position.

The TEG design temperature of the damper module shall be 50°C [90°F] higher than the highest TEG temperature specified on the requisition.

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Damper shaft drives may be electric motor or pneumatic. Hydraulic actuators are subject to the consent of the Principal.

In auxiliary fired HRSGs with fresh air operation, the transition time for the TEG/air change-over damper shall be as short as possible (less than 10 s for GT's <75 MW; less than 20 s for GT's >75 MW).

Actuators shall be capable of developing at least 110 % of the force required by the damper under the most severe operating condition.

The equipment for manual operation shall be easily accessible. A shaft-mounted position indicator shall be included which is clearly visible during manual operation, and from grade level. 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. Couplings in the transmission shaft(s) shall be all-metal and flexible.

The maximum blade travel in both directions shall be controlled by limit switches. 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. Unless specified otherwise, limit switches shall be contact free, rigid and robust. Location and orientation of limit switches shall not be effected by thermal expansion of the blade and the shaft.

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

Spade plate isolators may be applied if 100 % gas tightness is required.

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.

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.

Unless otherwise specified, spade plates shall be designed in stainless steel.

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.

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).

2.4.8 Stacks

The installation shall have its own boiler stack and, where specified, 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.

By-pass stacks shall be provided with a "top hat" or other suitable provision to prevent the ingress of rain. In dry climates, the Principal may specify internal rims complete with adequate drainage facilities or an automatically draining by-pass damper as an alternative.

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). The ports shall have blind flange bolted covers with chains. 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.

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

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base. In case (sulphur) dew points issues play a role, the insulation shall be adapted to keep the stack metal temperature above dew point.

- A continuous emission monitoring system (CEMS) shall be supplied if specified by the Principal.

The minimum stack height shall be as specified by the Principal.

2.4.9 Expansion joints

Fabric type expansion joints, or steel-bellows type with inner sleeves, shall be applied.

Steel-bellows type expansion joints shall be equipped with a shield to prevent rain, cooling the bellow or to protect the bellow for mechanical damage.

Fabric expansion joint(s) shall be a flexible multiple layer type based on the Supplier's standard design practice and made from materials with a history of successful operation in gas turbine systems.

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

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.

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

2.5 AUXILIARY FIRING SYSTEM

2.5.1 General

- The Principal shall state whether the boiler is to be equipped with auxiliary firing.

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. An in-duct register type or conventional register type, adapted for TEG, may be applied if considered more suitable for the particular boiler design (water cooled furnaces). The latter requires the approval of the Principal.

The firing system shall be designed for gaseous fuel only.

The fuel properties shall be specified by the Principal. If the fuel composition is variable, the range shall be specified by the Principal, and the Manufacturer/Supplier shall design the system to achieve the required boiler performance with any fuel composition within the specified range. Also, safe start-up using any fuel composition within the specified range shall be possible.

Minimum requirements for the control and safeguarding of the auxiliary firing system are defined in (Appendix 4).

2.5.2 Main burners

Reliable operation of the burners, without harmful flame impingement, flame carry-over from the combustion chamber, or flame instability is essential. These requirements shall apply with any fuel specified by the Principal, over the whole operating range.

Provisions shall be made for the installation of flame detection equipment on each register type burner and each row of a matrix burner; see also (2.5.3). In the positioning of the nozzles for this equipment, account shall be taken of the fact that one and the same flame detector shall be used to detect both the ignition flame and the main flame.

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The flames shall be stable and not blow off on any specified fuel whenever there is a minimum load on the burner together with the maximum turbine exhaust gas flow that can arrive at the burner.

The stability of the flames and the ability of the flame detection system to detect and discriminate between burners shall be proven during commissioning for a load range of 10:1.

Burners and associated equipment shall be capable of withstanding the maximum TEG temperature when not firing, and maximum temperature/back-radiation when firing.

Burners shall be sized for the most demanding design case with a design margin of 10 %. No allowance shall be included for burners out of operation.

2.5.3 Ignition unit

Each register type burner, and each row of a matrix burner, shall be provided with its own fixed ignition unit which shall include a transformer, spark igniter and an ignition burner, all suitable for intermittent operation in pressurised combustion chambers and under continuous exposure to TEG. The ignition burner shall be designed to have only one fixed position with respect to the main burner and shall have a pressurised air supply.

The main flame detector shall be installed so that it can also detect the ignition flame. Ionisation detection shall not be applied.

- The Principal shall specify whether the ignition units are to be fed from an independent fuel supply system, e.g., a battery of gas cylinders located at ground level or a dedicated natural gas supply.
- Continuous pilot burners shall be supplied only if required by the applicable regulations or if specified by the Principal. The design specification of continuous pilot burners shall be approved by the Principal.

Pilots and igniters shall be online removable and guide tubes shall include a non-return valve to avoid hot TEG leaving the ducting.

The flames of ignition and pilot burners shall be stable and not extinguish on any specified fuel, in the event of the maximum TEG flow arriving at the main burners. The minimum capacity shall be 0.5 % of burner duty with a minimum of 22 kW [75000 Btu/h].

Ignition units and pilot burners shall be of a type approved by the Principal.

2.5.4 Burner piping

Piping and piping connections in the immediate vicinity of the burners are considered part of the burner supply. The lay-out shall be clear and simple and the piping shall be robust, accessible and vibration-free.

Piping shall not obstruct access doors, observation windows or burners, and shall not hinder operation of the boiler or burners. Piping shall not run through ducting.

Flexible metal hoses are permitted for the ignition burners, pilots and, if required, auxiliary air for the burners. Flexible hoses may be used in the main burner fuel lines in case expansion issues of piping exist, however, the type of flexible hoses shall be of a type approved by the Principal.

In case Manufacturer/Supplier intends to use flexible hoses for main burner piping, it shall be ensured that the flexible hoses:

1. Are as short as possible;
2. Are suitable for a pressure 1.5 times the maximum operating pressure (with a minimum of 1 bar [14.5 psi]), at the maximum and minimum operating temperatures;
3. Have a directly accessible, upstream manual shut-off valve;
4. Are mounted in such a way as to avoid distortion, whiplash and damage;
5. Have end fittings as integral parts of the tubing;

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