Miscellaneous ancillary equipment 12

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Chapter outline

12.1 Introduction

Just as there are many configurations of the basic HRSG, there are also many different types of ancillary equipment that may be necessary to integrate the HRSG to a specific job site or application. These items may be installed internally within the HRSG gas path or externally to the HRSG casing (Fig. 12.1).

12.2 Exhaust gas path components

12.2.1 HRSG inlet duct design and combustion turbine exhaust flow conditioning

12.2.1.1 Combustion turbine exhaust characteristics

The combustion turbine's high mass flow and temperature combined with the turbine's complex exhaust outlet geometry lead to very turbulent flow conditions

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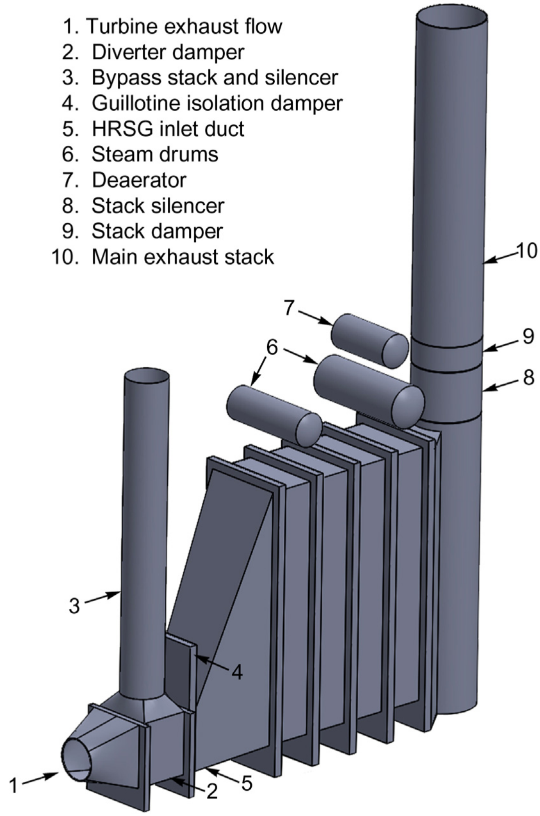

Figure 12.1 HRSG configuration.

entering the HRSG (see Item 1 of Fig. 12.1). This results in highly time-variable dynamic pressures on the HRSG inlet duct components.

12.2.1.2 Inlet duct configuration and mechanical design requirements

An aerodynamically perfect inlet duct would have a gradually expanding cross section, which would allow the flow patterns to coalesce and would reduce static pressure loss or even provide static pressure regain. The constraints of the modern market seldom allow this costly luxury. The modern HRSG has an inlet duct that is compromised by the desire to reduce overall length and thus material costs. A shorter inlet duct also reduces the plot area of the installed HRSG.

The HRSG inlet duct must be designed to resist the flow-induced forces upon it. These include the static back pressure resulting from the pressure loss through the downstream HRSG components as well as the varying dynamic pressures of the exhaust flow-induced turbulence.

12.2.1.3 Exhaust flow conditioning

A typical HRSG's performance is often thought to be self healing with regard to exhaust mass flow or velocity variations. In other words, a high flow in one region of a heat transfer module will result in higher heat transfer and will offset lower heat transfer rates in other regions of the same module.

But what happens to other devices within the HRSG? Supplementary firing equipment (duct burners) and emissions control catalysts often base their performance guarantees on even or minimally varying flow maldistribution characteristics at the entrance plane of the device.

What can be done to redistribute the uneven flow exiting the combustion turbine or to correct the flow maldistribution? Generally, there are two different methods, each with their own costs and benefits.

A single or multiple vane or airfoil array is sometimes used. These generally have a minimal effect on static pressure loss in the exhaust stream and, when properly designed, can provide flow straightening without adding substantial and costly structure within the duct. Unfortunately, poorly designed vanes can be at risk of mechanical failure resulting from fatigue caused by flow vortex shedding-induced vibrations. Since the observed incidence of vane failures is quite high, this seems to indicate that a successful design may not be easy.

Constant or variable porosity perforated plates (distribution grids) can also be installed across the full cross section of the inlet duct. This configuration is generally more mechanically robust than a vane array. This comes at a higher initial cost because of the larger mass of material required to span the duct where the grid is located. Also, because the grid design requires a static pressure loss across the entire plate to force the necessary flow redistribution, the grid will always have a larger permanent static pressure loss than a properly designed vane assembly. Variable porosity plates do, however, have an advantage in the ease with which the porosity can be modified in the field, usually with additional blocking plates, to revise flow distribution.

There are also installations that utilize a combination of these methods.

How do we determine the configuration of the flow-conditioning devices?

The old standby was to install an intuitively designed device, either an elaborate vane array or a highly restrictive, high-pressure drop distribution grid. Sometimes these worked, sometimes they didn't.

Very good results can be obtained through physical, cold flow scale model testing. This testing utilizes an ambient temperature fan forced air flow through a mostly transparent scale model of the unit under consideration. For the best tests, the flow is conditioned by a simulation of the combustion turbine outlet geometry before entering the HRSG model. Flow within the model can be visualized with smoke plumes or with simple tufts. Flow velocities and directional vectors can also be measured. All measurements are analyzed and compared to the actual HRSG through proven scaling equations. These models provide very good visualizations of the flow. The drawbacks to this style of testing include long model construction lead times, inaccuracies resulting from incorrect turbine outlet/HRSG inlet flow simulation, and the inability to represent flow changes resulting from temperature changes (i.e., the duct burner) within the actual HRSG.

Computational fluid dynamic (CFD) modeling has become more prevalent due to the increasing availability of lower-cost, higher-powered, multicore computing devices. These models can generally be produced faster than the cold flow models and also offer good visualization of the flow. Temperature effects can also be included in the model. The results, however, are often flawed by simplistic or erroneous turbine outlet/HRSG inlet flow condition assumptions, sometimes provided (but seldom guaranteed) by the combustion turbine manufacturer.

When modeling flow within an HRSG, it is advisable to periodically compare physical cold flow modeling to CFD modeling of the same unit to ensure the results correlate.

12.2.2 Outlet duct and stack configuration and mechanical design requirements

The material cost of a stack will vary directly with the diameter and height of the stack and the mechanical forces acting on the stack during operation.

The height and diameter of the stack is generally determined by emissions concerns, noise requirements, and pressure drop limitations.

For any given stack exhaust temperature and mass flow, the stack outlet exhaust plume will be influenced by the exit velocity and stack exit height. Because this plume aids in the dispersion of stack pollutants, which reduces the local ground level contamination, the plume dispersal requirements are usually dictated by the local pollution control agency.

Emissions monitoring requirements are also dictated by the pollution control agency having jurisdiction. Typically, continuous emission monitoring (CEM) equipment is installed a minimum of two equivalent diameters above any upstream flow disturbance or obstruction and one half diameter below the stack outlet.

The stack height may also be affected by the installation height requirements of exhaust silencing baffles or exhaust isolation dampers.

The mechanical design requirements also increase when the stack height increases.

Because of the height of the stack, wind and seismically induced forces on the stack determine the mechanical design criteria of the stack structure. These forces are usually defined by local building codes. Additionally, the initial design of the stack will include a thickness margin to accommodate future stack corrosion degradation.

The stack design is also influenced by mechanical resonance induced by external airflow (wind) vortex induced vibration. This flow-induced vortex pattern creates areas of low pressure on alternate sides of the stack, which causes the stack to vibrate from side to side. It is important to reduce these pressure forces if the frequency of the induced vibrations are near the resonate frequency of the stack. Strong vortex shedding may be reduced by using either aerodynamic strakes or a tuned mass damper.

Strakes are either a series of fences arranged in a helical array around the circumference of the stack or corkscrew-shaped fins in the same location. In either case, the strakes are placed within the top 20% of the stack height. The strake height is typically 0.1 times the diameter of the stack and the pitch is five times the diameter. Although the strakes can actually increase the lateral forces on the stack, it is important to remember that the magnitude of this force is generally a very small percentage of the wind drag forces on the stack.

A tuned mass damper is a system of added mass, typically a cylinder larger than the stack diameter, which is attached to the top of the stack by springs. Both the mass and the springs are designed to provide damping at the resonate frequency of the stack. A tuned mass damper is usually more costly than strakes and has a smaller effective range of damping.

12.2.3 Exhaust flow control dampers and diverters

Mechanical dampers can be used within the exhaust flow stream to either modulate for control of the exhaust flow within the HRSG or to securely isolate portions of the HRSG gas path from hot turbine exhaust.

12.2.3.1 Isolation dampers

Isolation dampers are either parallel multiblade louver dampers (see Item 9 of Fig. 12.1) or guillotine-style (see Item 4 of Fig. 12.1) single-blade dampers.

Guillotine dampers generally provide tighter shutoff than multiblade louver dampers and would generally be found downstream of a diverter damper assembly to provide positive isolation of the HRSG. This is especially important for safety when work must be performed within the HRSG while the combustion turbine is in operation with exhaust flowing to bypass.

Louver dampers are usually located in the main HRSG exhaust stack to retain heat when the system is not operating. In this application, the damper is only required to resist the rising stack effect flow and thus its sealing system is not as complicated as other damper applications. Stack dampers generally are designed with a linkage system that allows one or more blades to open with the differential pressure associated with a turbine startup. This is intended to prevent damage to the combustion turbine. In practice, this feature is seldom tested because of the possibility of turbine damage should it not work.

12.2.3.2 Flow diverter dampers

A diverter damper (see Item 2 of Fig. 12.1) may be installed between the combustion turbine and the main HRSG inlet duct to direct turbine exhaust flow to atmosphere through the bypass stack (see Item 3 of Fig. 12.1), to the HRSG, or to a combination of these two. They are typically used to allow a rapid startup of the combustion turbine by avoiding the necessity of lower temperature ramp rates required by thick metal components within the HRSG. Once the turbine is operating at base load, the diverter damper may be incrementally opened to modulate the hot exhaust flow into the HRSG. When the HRSG reaches full load, the damper is required to direct all exhaust flow to the HRSG by fully sealing the flow path to the bypass stack.

The diverter damper typically uses a single, pivoting "flap"-style blade to provide the flow control. Because this blade must be designed to function within the highly turbulent flow downstream of the combustion turbine and must accommodate differential thermal expansions, it usually consists of two metal faces supported by a structural array and separated by insulation.

The damper blade design will include a system of seals around the perimeter of the blade. These may be mounted either to the blade or to its support plenum. Both resilient gasket seals and flexible metal leaf seals have been used successfully in this application.

12.2.3.3 Damper actuation

All damper systems operate in response to an on—off or modulating electrical signal from the plant control system. This signal will cause an electric, pneumatic, or hydraulic actuator to act on the damper blades through a system of linkages. It is important that the actual position of the blade be fed back to the plant control system by limit switches (open—closed damper systems) or by position transmitters (modulating damper systems).

12.2.3.4 Damper seal air systems

Some applications require the damper to include a plenum between two rows of seals to contain a pressurized flow of ambient air, which serves to further limit the possibility of hot exhaust gas leaking by the seals. These systems are sometimes referred to as leakproof or man-safe but their actual effectiveness is largely based on the "as new" condition of the seals and the alignment of the blades, which tend to deteriorate with operation thus reducing their effectiveness.

12.2.4 Acoustics

The major noise source at an HRSG installation is that generated by the combustion process within the turbine or the exhaust flow noise within the turbine or HRSG. The intensity of the noise generally varies directly with the size or power of the turbine. Through experience, the expected (but seldom guaranteed) turbine outlet sound power values provided by the various turbine manufacturers tend to include significant additional margin. The example below shows one turbine manufacturer's octave band sound power level spectrum (L_w, dB re 10^{-12} W) definition for a nominal 200-MW combustion turbine. This is equivalent to an overall A weighted average of 144.4 dBA.

Combustion turbine sound power levels (L_w, dB re 1 pW)

OBCF, Hz	31.5	63	125	250	500	1000	2000	4000	8000
Sound power	143	148	149	145	135	137	137	136	136

Gas turbine acoustic emissions radiate from two principal sources from HRSGs: the stack exit and the casing surfaces. Stack exit noise emissions are dependent on the stack geometry and the substantial acoustic attenuation provided when the turbine exhaust sound power is converted to thermal energy during passage through the HRSG heat transfer tube field array. Casing radiated noise emissions are dependent on the wall construction (principally the surface mass and outer plate coincidence frequency) and the attenuation by the tube field array. In many cases additional noise mitigation measures, such as sound absorption baffles or acoustic shrouds, are installed to reduce acoustic emissions downstream of the baffles or outboard of the shrouds.

The turbine outlet sound power radiates from the HRSG stack outlet or through the casing wall panels to the measurement point of interest where it can be measured as a sound pressure level (L_p, dB re 20 μPa).

12.2.4.1 Casing radiated noise

Some sound power travels through the HRSG casing panels and is radiated through the air. This sound power is generally blocked by local plant buildings or structures and typically only results in localized near-field noise concerns. In cases where the HRSG is the dominant structure, however, the casing radiated noise can influence the far-field noise measurements.

For example, with the turbine outlet sound power as described above and a typical HRSG configuration with ¼″-thick exterior casing panels, the near-field sound pressure level external to the inlet duct is predicted to be 80.1 dBA at a 3-ft distance from the casing.

12.2.4.2 Stack radiated noise

As the turbine outlet noise travels through the HRSG on its way to the stack outlet, portions of the acoustic sound power are attenuated during passage through the HRSG heat transfer coils. The remaining acoustic energy spreads hemispherically from the stack outlet through the air to be measured at the far-field point of interest.

With a turbine outlet sound power as described above and the attenuation of a typical HRSG, the far-field sound pressure level as measured 400 ft from the HRSG stack is predicted to be 54.0 dBA.

12.2.4.3 Attenuation methods

In addition to the attenuation provided by the HRSG tube field, further acoustic attenuation can be provided:

- The turbine sound power can be attenuated when entering the HRSG through parallel baffle acoustic absorber panels located within the inlet duct exhaust flow field. Silencing in this location provides the immediate effect of attenuating all noise downstream of the silencer. This may result in reducing the required casing thickness or eliminating the necessity of external noise shrouds. Unfortunately, because of the high-temperature, high-velocity turbulent exhaust flows in this location, baffle material costs are high and their operating life is usually limited with noise attenuation properties decreasing over time. Also, baffles in this location typically require a higher gas side pressure drop.
- Casing radiated noise can be reduced by increasing the mass (thickness) of the HRSG casing or adding acoustic shrouds adjacent to portions of the HRSG exterior. Adding casing thickness will always increase the initial cost of the HRSG but its effectiveness will be constant throughout the life of the unit. There are times when external shrouds are the only method of meeting acoustic goals. These increase initial cost, take up valuable space, and restrict access. When uncertainty exists about their necessity, provisions (space) can be allowed during design to allow for future retrofit of acoustic shrouds.

- Where stack noise is of concern, parallel baffle acoustic absorber panels can be located within the ducting between the HRSG heat transfer modules and the stack or inside the stack cylinder (see Item 8 of Fig. 12.1) itself. As an example, the addition of minimal length stack baffles to the HRSG example above is predicted to reduce the far-field sound pressure level from 54.0 to 47.0 dBA. Because of the lower temperatures and more uniform exhaust flows in the stack, baffles located here can be fabricated of lower-cost materials and generally exhibit a longer life than inlet duct baffles. Their use, however, will always increase the height of the stack necessary to allow for proper location of the continuous emissions monitoring ports. As above, where uncertainty exists about their necessity, provisions (space) can be allowed during design to allow for future retrofit of stack baffles although this will still require increasing the stack height.

12.3 Water/steam side components

12.3.1 Feedwater pumps

Within an HRSG system, a feedwater pump is used to move boiler water from the deaerator/LP steam drum (see Items 6 and 7 of Fig. 12.1) to the higher pressure levels (HP and IP) of the HRSG.

All pumps are made up of a rotor with one or more impeller stages housed within an axially split, barrel, or ring segment casing. These pumps are generally directly coupled to the drive motor and therefore operate at constant speed. Variable speed pumps can be provided and are more efficient but much more costly.

One or more pumps will be supplied per HRSG, each rated for 50% or 100% duty. Additional flow capacity for non-HRSG usage is generally not included in the pump design.

The pump will be mounted complete with the electric motor driver on a common baseplate. An automatic recirculation (ARC) valve will be supplied and incorporated into the pump outlet piping to ensure a minimum flow through the pump to prevent cavitation. The flow from this valve is returned to the LP drum. IP feedwater will either be extracted from an interstage nozzle on the HP pump casing or will be let down from the HP pressure downstream of the pump discharge nozzle. Pump skids will be designed for outdoor installation in a nonhazardous area classification.

12.3.2 Deaerator

Depending on the source of feedwater/condensate to the HRSG, it may be necessary to remove dissolved oxygen and carbon dioxide from the water. Fortunately, Henry's law of partial pressures (the solubility of any gas dissolved in a liquid is directly proportional to the partial pressure of that gas above the liquid) allows for that removal. A deaerator sprays the incoming feedwater into a steam environment in which the partial pressures of the gases are reduced. This water is further cascaded over a series of trays while still in the steam environment and eventually flows out of the deaerator while the oxygen and carbon dioxide are vented to atmosphere. This also raises the temperature of the feedwater to close to the saturation temperature of the steam environment.

For most HRSG installations, the deaerator vessel (see Item 7 of Fig. 12.1) is integrally linked to the steam drum of the low-pressure section of the HRSG. This steam drum also serves as the storage tank for the feedwater pump suctions to the higher-pressure portions of the HRSG.

12.4 Equipment access

12.4.1 External access

All equipment external to the HRSG that requires periodic maintenance should be accessible from permanent platforms. These platforms should be readily reached through permanent stairways, ladders or, in rare instances, elevators. For safety reasons, all maintenance platforms require a minimum of two separate means of egress.

The majority of equipment on a modern HRSG requiring permanent access will be located at the top of the unit surrounding the steam drums. This includes valving and instrumentation required for control and monitoring of the steam and water flow in the HRSG. The remainder of the permanent access requirements will be on the exhaust stack (damper actuator access or CEM system access), arrayed along either side of the HRSG at various elevations or at grade level.

Experience has shown that a freestanding stair tower providing the primary means of access may initially be more expensive than stairways supported from the HRSG casing but usually provides substantial labor savings when installed during the initial HRSG construction phases.

12.4.2 Internal access

Most equipment within the HRSG enclosure will require access for occasional inspection or repair. This access is typically provided by temporary means such as field-installed stationary scaffolding or cable-suspended mobile scaffolding man lifts. Both methods have benefits and drawbacks. The stationary scaffolding is costly and requires substantial installation time and cost. The suspended scaffolding platforms can only be used where their support cables can be readily accessed from the HRSG roof casing. Equipment such as duct burners or emission control catalyst requiring frequent inspections are best served by suspended scaffolds but their installation requirements require careful planning during the design phase of the HRSG.

12.5 Conclusion

Modern HRSGs are complex systems requiring careful design coordination of all individual components. Each individual job site is different and may require some or all of the equipment described in this chapter. As future requirements change, even more equipment may become standard. This ever-changing nature will always provide opportunities for the talented HRSG design engineer.