Modular once-through boiler for flexible small-scale combined cycle

Small-scale combined cycle plants (< 100 MW) answer the demand for highly flexible distributed generation and integration with intermittent renewable power sources. However, conventional heat recovery steam generators (HRSGs) with drum boilers hinder owners from enjoying the flexible, fast-responding power generation a modern grid system demands. John Cockerill Energy's vertical-exhaust-gas-flow once-through boilers enable quicker combustion turbine startup/shutdown and transient response to grid demand and employ a modular design that results in lower construction costs than conventional field-erected HRSGs

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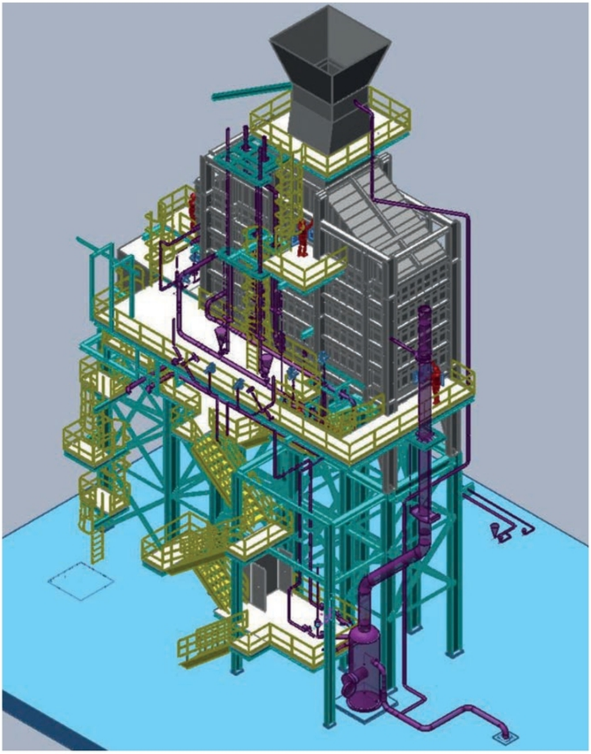


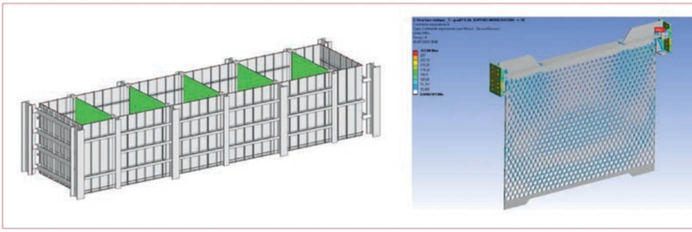
Above: **Figure 1. JCE vertical OTB design (dry operation mode). Note the significantly reduced amount of external piping, the lack of multiple boiler drums and associated piping and valves and the reduced number of modules. In this depiction, there is a single inlet plenum, a single level for the OTB module, and the exit plenum and stack.** Source: JCE

HRSGs are employed in distributed generation applications for small-scale (less than 100 MW) combined cycle and cogeneration facilities and are also found on floating LNG (FLNG) platforms that liquefy, store, and transfer LNG. A shared requirement is a demand for lower life cycle cost designs that will operate reliably and efficiently for many years. For offshore projects, weight and volume also are important HRSG design considerations, in addition to equipment footprint. HRSG specialist John Cockerill Energy (JCE) – formerly CMI – has introduced a new vertical modular once-through boiler (OTB) that will change how small-scale power generation and FLNG projects could be designed in the future.

The HRSG is the heart of every plant designed to recover waste heat from the exhaust stack of a combustion turbine (CT). For distributed generation applications, the slow thermal response of the conventional HRSG during startup/shutdown and transients is a significant performance limitation of the plant. The solution to this challenge is an HRSG design that increases plant reliability through reduced steam generator design complexity and can routinely perform rapid startups, shutdown, and transient operations without loss of service life. The JCE vertical OTB meets these design requirements. It also uses modular fabrication to reduce factory and field erection time and cost. Figure 1 shows the JCE vertical OTB design.

Modular design

Traditional horizontal or vertical HRSGs with drum boilers have been widely employed for many years. Distinct economiser, evaporator, and superheater sections within a conventional HRSG require significant external piping, instrumentation, and controls, as well as many individual sections that must be separately field erected and seam welded. Temperature limits within each section are strictly controlled so as to avoid thermal damage to the heat transfer surfaces and routine cycling of these plants will reduce HRSG life.



Above left: **Figure 2. A typical vertical OTB module during fabrication. The width of the single wide module is about 4.5 m, an important dimension for shipping considerations. Dual-pressure OTBs are also available, with the separate serpentine tube systems arranged within a single module.** Source: JCE

Above right: **Figure 3. Tube sheets, providing tube support, are integrated into the modular box, with constant tube pitch. The tube sheets employ cantilever supports bolted on main columns and main stiffeners.** Source: JCE

Thick-walled high-pressure drums limit the rate of change of pressure during startup and transient operation and thus slow plant startup and limit plant ramp rates. Also, some regions have imposed restrictions on emissions during startup that further limit plant operating flexibility with conventional HRSGs.

JCE's vertical OTB design heats, vaporises, and superheats water in a single serpentine tube bank, eliminating the traditional independent economiser, evaporator and superheater sections that are interconnected via a high-pressure steam drum entailing extensive piping, with numerous downcomers and valves, replicated for each operating pressure level.

Because the OTB can run dry, the high-maintenance bypass stack and silencer found in conventional plants are not required. The resulting footprint reduction is particularly important for sea-borne applications.

The small OTB only requires the fabrication of a single pressure part module, further reducing the construction cost and shortening the erection schedule. A single OTB module is shop fabricated and shipped with the serpentine tubing and tube sheets installed and fully pressure tested before shipping (Figure 2).

The modular nature of the OTB permits a very straightforward assembly sequence. Note that the structural steel requirements are reduced because there is no need to hang multiple heavy boiler drums and the external piping is significantly reduced. A single-pressure-part-module OTB requires only three to five weeks for erection, including platforms, stairs, and seal welds (Figure 3).

Unique features

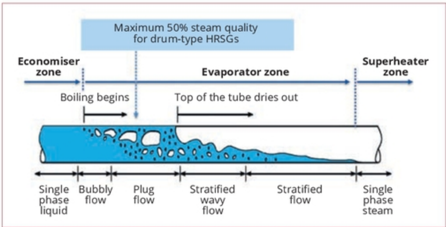
Dry startup and operation of the OTB is a unique feature that is unavailable with conventional drum type HRSG designs. Precious minutes and expensive fuel are wasted when combustion turbines must idle or remain at an inefficient reduced load to preheat the HRSG. With an OTB, the CT is started and run according to OEM-specified ramp rates without concern for steam temperatures or pressures. The OTB may be started or shutdown at any time without reducing the combustion turbine load. If the plant is configured with a steam turbine, then initial steam production from the OTB is desuperheated and bypassed to the condenser until steam temperatures and pressures suitable for the steam turbine are reached and then steam is introduced into the turbine. Likewise, steam production can be suspended at any time without reducing CT load.

In addition, the OTB can operate down to as low as 30% of CT load while maintaining steam superheat temperature. The OTB has low thermal inertia and is thus able to quickly respond to changes in the CT gas flow and temperature. The quick system response is primarily enabled by the elimination of the thick-walled boiler drum(s) that are thermally slow in response to inlet gas temperature changes. The net effect is complete de-coupling of the CT from the steam cycle, allowing the CT to maintain its quick-start capability in response to load changes or transient grid conditions. This feature is particularly useful when dealing with intermittent renewables on the power grid.

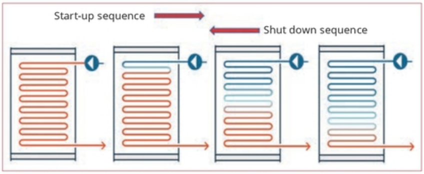
The vertical OTB is designed to start dry and then transition to steam production by introducing water into the tubes that are at exhaust gas temperature. As already noted, the water is heated, vaporised, and superheated in a single serpentine horizontal coil bank (Figure 4).

Unlike a conventional HRSG in which saturated steam bubbles are produced and collected in the steam drum and then sent to a separate superheater, the OTB produces saturated and then superheated steam within the same tube bank. The effective length of the horizontal tube bank is determined by the combustion turbine heat source. With the OTB design, boiler efficiency is improved as there is no approach temperature associated with pressure drums. Startup and load transient response is no longer limited by drum metal temperatures as the vertical OTB may be started and run dry.

Steam superheat conditions are determined by controlling the flow rate of water entering the OTB, with or without the need for a desuperheater, depending on the application. Of particular interest is the hot start sequence.



Above: **Figure 4. The vertical OTB does not require multiple tube bundles as found in the typical HRSG. Instead, a single tube section serves as a combined economiser, evaporator, and superheater. The OTB eliminates the need for steam drum(s) and other related piping and instrumentation.** Source: JCE



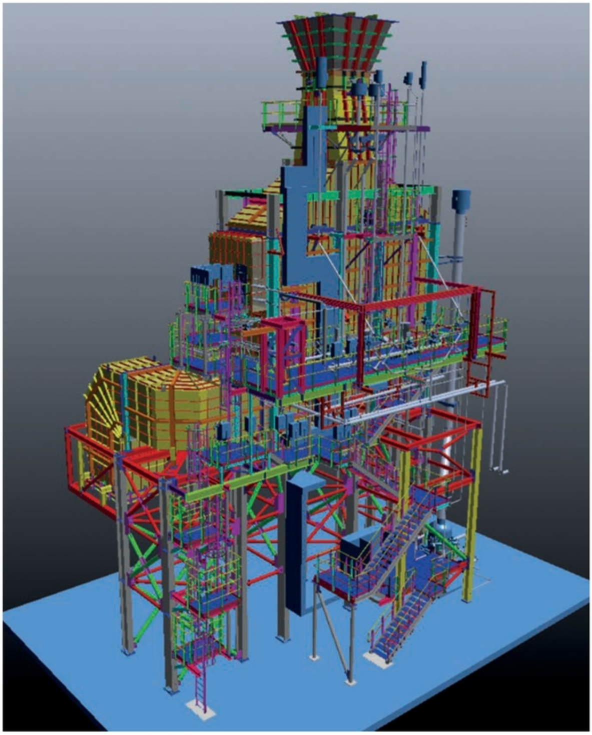
Above: **Figure 5. Unlike a traditional HRSG with separate tube banks for the economiser, evaporator, and superheater, a vertical OTB performs all these functions within a single serpentine tube bank. The "dry out" zone, the point within the tube bundle where saturated steam transitions to superheated steam, will move based on CT load. The illustration shows how tube metal temperatures respond during a hot startup and a shutdown sequence.** Source: JCE

With the CT at full load and the OTB at exhaust gas temperature, the OTB control system initiates operation by adding feedwater at an initial low flow, increasing according to a defined ramp rate until the inlet rows of the OTB are cooled by the feedwater. When a tube metal temperature gradient develops, then the OTB stack temperature will begin to drop.

When the OTB reaches full steam production the OTB control setpoint switches to temperature control based on tube metal temperatures and various control algorithms. At this point, the temperature profile will be achieved and the stack temperature will normalise. In addition, the location of the "dry-out zone" (the location within the tube bank where saturated steam becomes superheated steam) will also stabilise. When the CT load is reduced, the control system follows by reducing feedwater flow so that the superheat temperature remains constant, although system pressure will float. At reduced load, the dry out zone will move upstream, towards the economiser, using more of the OTB tubing to maintain the superheater setpoint temperature. When the CT load increases, the dry-out zone will move towards the superheater within the tube bundle (Figure 5).

Appropriate materials choice allows the OTB to run dry. Ferritic material, SA178A or SA213 (T11/T22), is the standard material for the tubes. If the OTB is going to be operated "wet", then conventional tube materials are used similar to those used in conventional drum type HRSGs. Naturally, tube and fin material selections are based upon the combustion turbine exhaust temperature, steam temperature and pressure, and evaporator inlet temperature.

The part of the vertical OTB that experiences the highest thermal stress is the tube sheet that supports the finned tubes, specifically the ligaments between the tube holes (see Figure 3). Finite element analysis was used to properly design these high-stress regions of the OTB dry operating mode. The tube sheets are fixed in place by tube sheet supports integrated into the modular box. The tubes are installed with constant tube pitch in both vertical and horizontal directions of these tubes sheets.



Above: **Figure 6. A project in Ghana, West Africa, is in the process of installing five JCE OTBs that will connect to a single steam turbine to convert the five existing simple cycle CTs into a combined cycle plant, adding 52 MW of much needed power to the grid. The arrangement of one of the five OTBs is illustrated. The plant employs vertical dry run OTBs with two pressure levels.** Source: JCE

For applications that require SCR (selective catalytic reduction), a separate empty module designed to accept field-installed catalyst sections can be inserted after the pressure part module. The SCR ammonia injection grid, located upstream of the catalyst, can be factory installed in the pressure part module.

In addition, supplementary firing of an OTB is also possible. The burner system can be installed in the inlet duct module located upstream of the first pressure part module.

The power generation industry has struggled for years to keep boiler water chemistry under control to minimise boiler tube pitting, corrosion, scaling, or carryover. Conventional drum boilers require water treatment chemicals, such as phosphate, and periodic blowdown for removal of suspended solids and bottom sludge, to avoid internal tube damage. The OTB eliminates this chemical treatment and blowdown systems thereby minimising the cost for treated condensate makeup. However, the OTB does require very clean water and a condensate polisher is typically installed between the condenser and the HRSG inlet. The net impact on the plant is a reduction in system maintenance and chemical treatment costs, while extending boiler life.

Case study: Ghana, West Africa

A power power plant is being built to supply efficient, reliable, low-cost power for Ghana's growing economy. The facility is currently being constructed in two phases. Stage 1A includes five fast deployment GE TM2500+ gas turbines running in simple cycle mode (the TM denoting the truck-mounted version of the familiar LM2500+). An added 52 MW of combined cycle capacity will be added in Stage 1B with the installation of a single steam turbine and five JCE OTBs (Figure 6).

The facility requires maximum operational flexibility with an extremely compressed construction schedule for the conversion of the already operational simple cycle CTs to combined cycle.

The OTB proved to be the ideal choice for the project based on its capability to run dry, as already noted, which de-couples the CTs from the steam cycle. The modular pressure part box OTB design maximises shop fabrication by enabling 100% of the pressure parts to be pre-assembled in a single module.

In January 2019, GE, the prime contractor, awarded John Cockerill Energy the contract for five dual-pressure OTBs. The JCE scope of work includes the design, engineering, manufacture, and supply of the boilers. The pressure parts were manufactured in modular box style in Korea. Boiler erection is being completed by Metka on behalf of GE.

The fuel for the plant is LPG, with distillate oil as backup. The steam conditions are 512°C/64.8 barA for the high-pressure and 232°C/4.6 barA for the low-pressure loop.

The plant is expected to run at baseload with periodic cycling operation.

Substantial completion of the plant is expected in December 2020.

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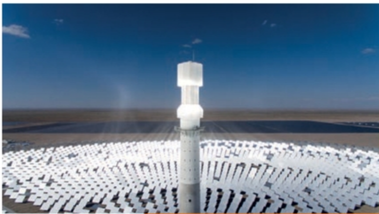

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