Once Through Steam Generator Tied to Gas Turbine(s) as a Compressor Drive

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INTRODUCTION

Current demands and future trends in natural gas transportation as well as the problems that Europe and the rest of the world have been facing in power generation, including efficiency and emissions are making combined cycle or cogeneration a logical choice. Waste heat boilers have been broadly recognized but not so widely used to resolve the mentioned problems in gas transmission facilities. Recently, an opportunity has been given to the Once Through Steam Generator (OTSG) in Europe to prove all its advantages. TransCanada gas pipeline operators, owners and customers have been benefiting from this technology for years.

It is well known that gas turbines are versatile and reliable energy sources for electricity generation, mechanical drives and propulsion. The facts are that gas turbine systems are capable of generating a large amount of power per unit of weight and (or) occupied space, have relatively simple operation and maintenance and high efficiency. In addition, gas turbines produce less air pollution and greenhouse gases for the same power output as compared to other conventional, fossil fuel burning power plants. These factors have resulted in gas turbines being the best choice for use in a wide range of applications, including pipeline compressor drives.

On a global level, we have finally recognized and started to cope with the pollution problems that are associated with the combustion of coal and oil, and there has been a tremendous increase in demand for cleaner and more advantageous types of fuels such as natural gas. Because of the increased demand, new pipelines are being built everyday in Europe, North America and Australia.

As new pipelines are being built, more and more gas turbines will be put into use. A tremendous amount of waste heat will be available from these GTs for combined cycles and cogeneration. Waste heat recovery boilers will be in very high demand. A unique type of HRSG is a Once Through Steam Generator (OTSG), which is a reliable and competitive product designed and manufactured by Innovative Steam Technologies (IST) Cambridge, Ontario, Canada. This boiler has many unique design features that complement its increased efficiency such as dry-running capability, the elimination of steam drums, reduced weight and simple operation.

The author of this article is witnessing a tremendous demand for quotations for OTSGs from all over the globe, and a record increase in orders. The reason for its popularity is that engineers have recognized all the advantages an OTSG offers to combined cycle applications, regardless of the gas turbine prime duty.

HEAT RECOVERY BOILERS (HRB) –BASIC

Heat recovery boilers have been used in power and process industry for many years. Over the years, engineers involved in their design and manufacture have done a remarkable job of optimizing HRB's. The focus and objective has been to improve the HRB's efficiency and ease of operation while allowing for higher exhaust gas mass flows and temperatures and increased steam parameters. The introduction of new and improved materials, operational feed backs and a more demanding marketplace have resulted in a large variety of quality heat recovery products. Until the OTSG was introduced, all HRSGs were following the same relatively complex design approach. This approach would always comprise of an economizer, evaporator and superheater as distinct components and drum(s) (Figure 5). A significant departure from this conventional HRB design is the OTSG with its simple, countercurrent flow heat exchanger that in one pass converts all feedwater into steam. In this boiler, preheating, evaporation and superheating consecutively take place in a series of long continuous finned tubes joined with u-bends forming a serpentine circuit (Figure 6).

Heating surface, tubing and tubing arrangement

A Heat Recovery Boiler or as it is frequently designated, a Heat Recovery Steam Generator (HRSG) is in essence sequence(s) of heat exchanger surfaces where the hot gas stream from incinerator gases, furnace effluents or most commonly gas turbine exhaust passes over tubes carrying water. The two involved mediums, gas and water, have different thermal properties. Exhaust gas has just a fraction of the specific heat compared to water side and therefore, in order to compensate for gas side thermal "weakness", fins are attached to the tubes to increase the heating surface area.

Solid fins are helicaly welded or brazed to the tubes. These fins are suitable for liquid fuels and provide better corrosion resistance. If the sheet metal strip is sliced part-way through at reasonable distances and spirally welded around the tubes we will get serrated fins which will further increase the heating surface but consequently increase the gas side pressure drop. These fins are prone to fouling and therefore not recommended for dirty flue gas and most liquid fuels.

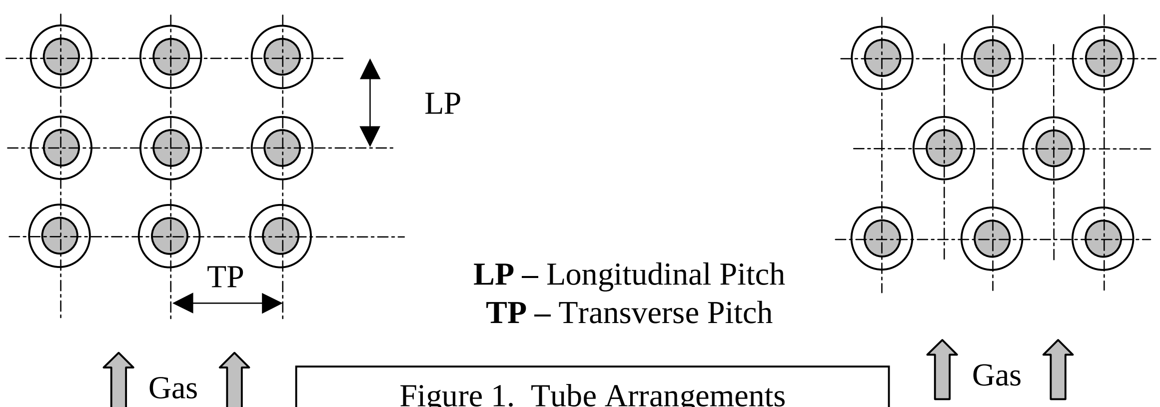


Figure 1. Tube Arrangements
(left) INLINE; (right) STAGGERED

When a stiffened tube is required, an L shaped strip might be coiled around the tube. Rarely used in HRBs but worth mentioning and offered in today's market are embedded finned tubes. A fin root is implanted in a grooved tube wall creating a high-strength connection, resistant to thermal movement and vibration.

Fins radically increase the heat transfer area on the gas side, and if compared to the internal tube wall area, the ratio ranges from 10:1 to 16:1. Fin metal temperature is not constant throughout. The highest temperature is at the tip, while the coolest temperatures are found at the root. Consequently the heat transfer efficiency is not the same as the tube itself. The efficiency is usually 55 to 85 %. Exhaust gases from gas turbines are usually at temperatures ranging from 400 ºC to 640 ºC. Steam temperatures generally used in steam turbines are slightly lower than the exhaust gas temperature indicated above.

Fins are made of either carbon or stainless steels. Carbon steel fins, because of their superior thermal conductivity, are preferred but sometimes stainless fins, whose conductivity can be as low as 40% of carbon steel, must be used in HRSGs. Selection is based on the exhaust gas temperature in the referenced boiler zone, the potential of condensation or acid formation, and the general ambient conditions.

It is also very important to select an appropriate number of fins per unit length. Use of dirtier fuels such as oil can cause clogging of the heating surface. A reduced fin pitch is a way of preventing the occurrence.

There are two arrangements of finned tubes used in a HRSG, as Figure 1 illustrates. The inline arrangement results in a reduced gas side pressure drop but also has a reduced heat transfer rate and will occupy more space. In comparison, a staggered arrangement provides better heat transfer and a more compact design, but will cause an increased gas side pressure drop.

Figure 2 is an actual photo of a rear end tubesheet holding staggered tubes of IST's single pressure OTSG. The picture also shows "u-bends" which connect individual tubes into a continuous water/steam flow path from feedwater header to steam header (not shown on this picture).

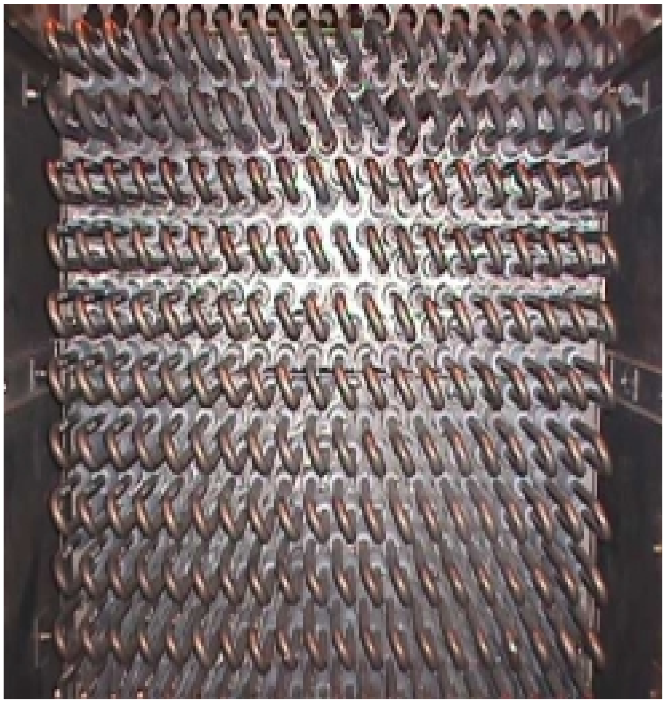


Figure 2.
Staggered Tubing Arrangement

Turning our point of view on finned tubes 90º compared to the previous figure we could recognize the following arrangements:

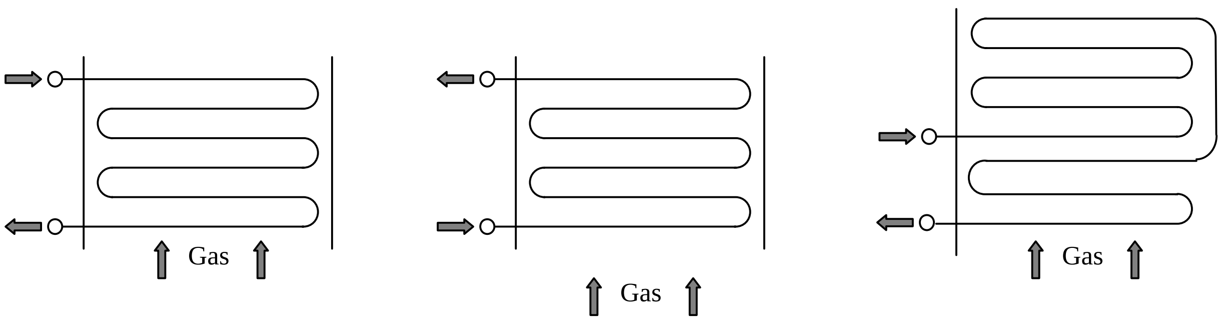


Figure 3. Flowpath Arrangements
(left) COUNTER; (middle) PARALLEL; (right) COMBINATION

Along the gas path throughout an HRB in different boiler sections we can find different flowpath tubing arrangements. The heat transfer rate and the flow stability both depend on the tube arrangement. Each indicated arrangement offers benefits and holds undesired overall effects and it is up to the HRSG designer to maximize the benefits offered by each solution and /or to find the best combination of all possible scenarios along the gas path throughout the unit (Figure 3).

The objective is to get the temperature profiles of the gas and water/steam to be as parallel as possible. At the same time the gas side pressure drop has to be kept within reasonable limits. A multiple pressure HRB will allow a better utilization of waste heat and as Figure 4 illustrates, the goal of achieving parallel lines has been achieved in this HRB - OTSG. It should be noted that the approach temperature (the difference between the water temperature leaving the economizer and the saturation temperature of the evaporator) does not exist on the diagram. The reason for this is that there is no distinct boundary between the economizer and evaporator section in an OTSG.

A very indicative parameter on the graph is the pinch point. The difference between the gas temperature leaving the evaporator section of the tube bundle and the saturation temperature corresponding to the steam pressure in that section defines the pinch point. A pinch point in the range of 10 to 30 ºC will result in technically and economically satisfactory design. In some specific situations, and traditionally in regions with a higher fuel price, a lower pinch point would be selected to maximize the plant efficiency. To lower the pinch pint, additional heating surface needs to be added which increases the capital cost. Attention needs to be paid to ensure that there is not an excessive gas side pressure drop consequent to the addition of heating surface. Even though the HRB efficiency will be increased, an overall plant efficiency might be reduced because of a reduced power output from the gas turbine generator.

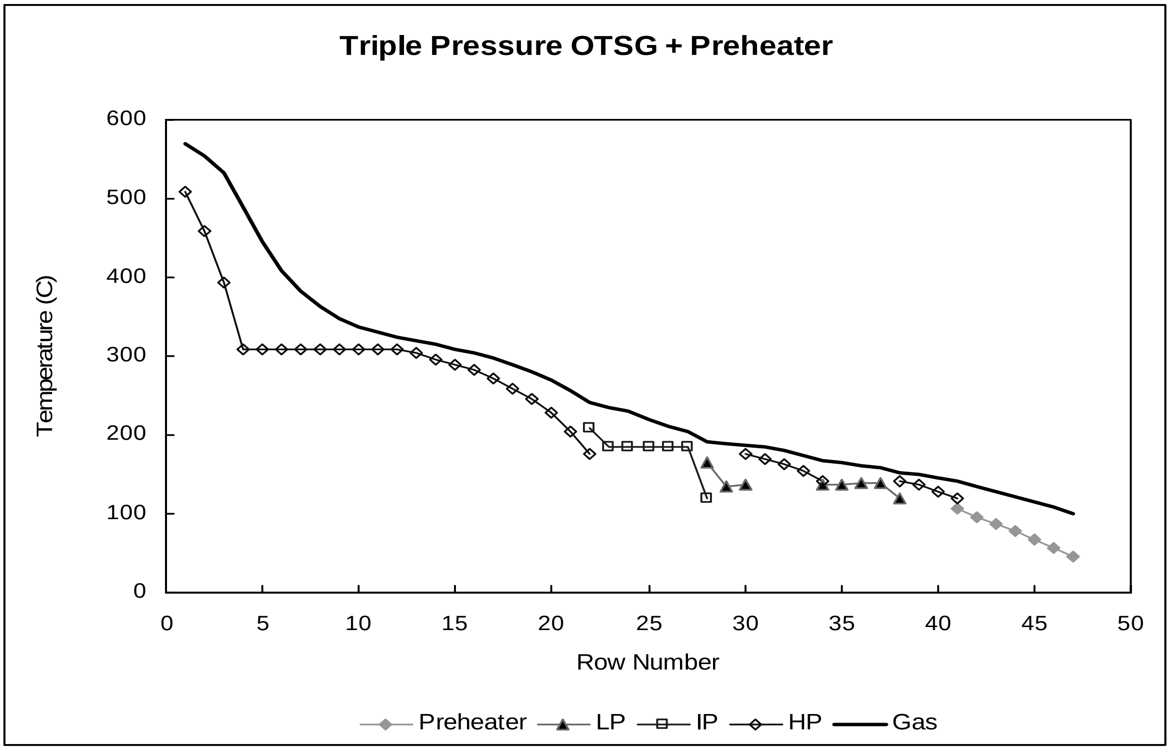


Figure 4. Water/Steam and Gas Temperature profile

Tube material selection is connected to the temperature that the metal is expected to achieve during operation. Generally, where the tube metal temperature is not expected to exceed 590 ºC, usually seen in an unfired HRSG, T22 (2.25% Cr – 1 Mo) or T11 (1.25 Cr – 0.5 Mo) will be used. If tubing needs to sustain a higher pressure and the same temperature as the previous category, T91, T92 or T93 (9 to 12 Cr) might be selected. For higher temperatures that are regularly seen in supplementary fired units, stainless steel tubing, commonly 304H (18Cr – 8 Ni), will be used. ASME named SB423 NO8825 (38-46 Ni – min 22 Fe - 19.5-23.5 Cr) and SB407 NO8800 (30-35 Ni – min 39 Fe - 19-23 Cr), or commercially known as INCOLOY alloy 825 and 800 are the only tubing material IST has been using in their OTSGs.

Alloy	800	825
Nickel	30.0-35.0	38.0-46.0
Chromiun	19-23	19.5-23.5
Iron	39.5 min.	22.0 min.
Carbon	0.1 max.	0.05 max.
Manganese	1.50 max.	1.0 max.
Sulfur	0.015 max.	0.03 max.
Silicon	1.0 max.	0.5 max.
Copper	0.75 max	1.5-3.0
Aluminum	0.15-0.60	0.2 max.
Titanium	0.15-0.60	0.6-1.2
Molibdenium		2.5-3.5

Ducting

Ducting is usually made of 6 mm thick carbon steel panels, gas tight welded on structural steel members that are insulated and lined. It continuously connects the waste heat source, commonly a gas turbine exhaust diffuser, heating surface (often referred to as pressure parts) and stack that outlets cooled gases into the atmosphere. Considerable attention has to be paid to the ducting design in order to reduce gas side pressure loss, avoid recirculating gas pockets and sudden changes in velocities. Insulation needs to prevent heat losses and accommodate limits on the outside wall temperature. Liner plates, 2 to 3.4 mm thick, strategically placed to allow thermal growth and sustain often very high gas velocity cover this insulation.

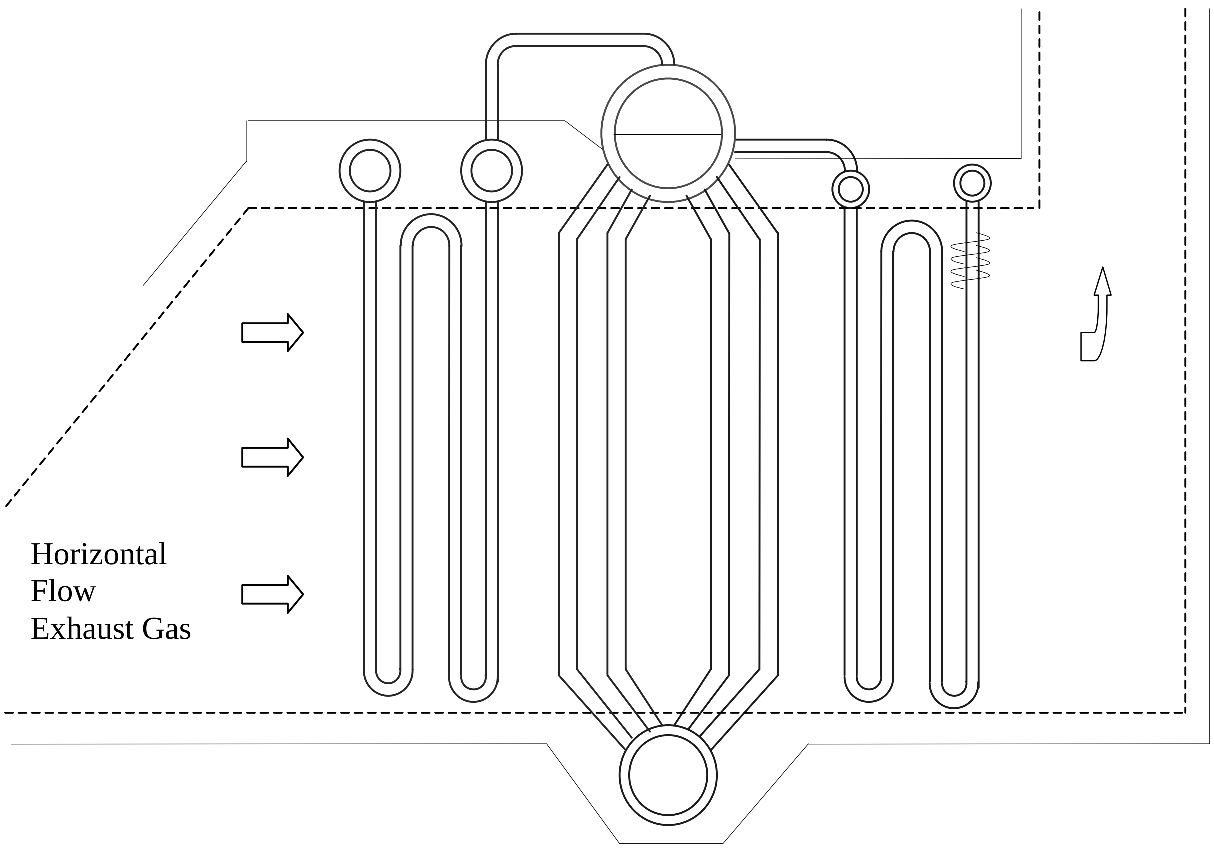


Figure 5. Conventional HRB design

Depending on the gas flow direction, two categories of HRSGs are seen in practice. Horizontal HRSGs, in which the exhaust gas flows horizontally over vertical tubes (Figure 5). The second type, more often seen in Europe, is a vertical HRB (see Figure 6). Each arrangement has advantages, but probably, after a detailed analysis the conclusion would be that both arrangements are equally justifiable.

In the early days, before assisted circulation was introduced in horizontal boilers to provide faster startup, vertical arrangement has been slightly beneficial. Nowadays, when this feature plays a role proponents of horizontal arrangement would say that a small pump could be used to start the circulation, and upon established desired flow, simply shut down. Probably the strongest argument for a vertical HRB is the fact that forced circulation allows implementation of smaller–diameter tubing, eventually resulting in a lighter and more economical boiler. Furthermore, if footprint plays a role in evaluation and selection, then vertical HRB selection becomes evident. This is the case in offshore applications and in heavily populated regions.

The gas side pressure drop, sometimes a neglected parameter, can influence the combined cycle power output. Over the years, the industry has become conditioned to accept HRSG system gas side losses of 250 to 305 mm H_2O. Ideally, the diffuser- type inlet duct should have half angles of 7.5º (15º included angle). However, the use of this angle in duct design would result in longer and costlier ducts in the horizontal arrangements. Often we will see a very aggressive half angle of 22.5º, three times the optimum, which provides little or no pressure recovery from velocity energy.

As environmental issues are receiving more attention, sometimes imposed by legislation, emission reduction systems are being incorporated more and more into combined cycle plants. It should be noted that SCR system can easily be incorporated into both horizontal and vertical arrangements.

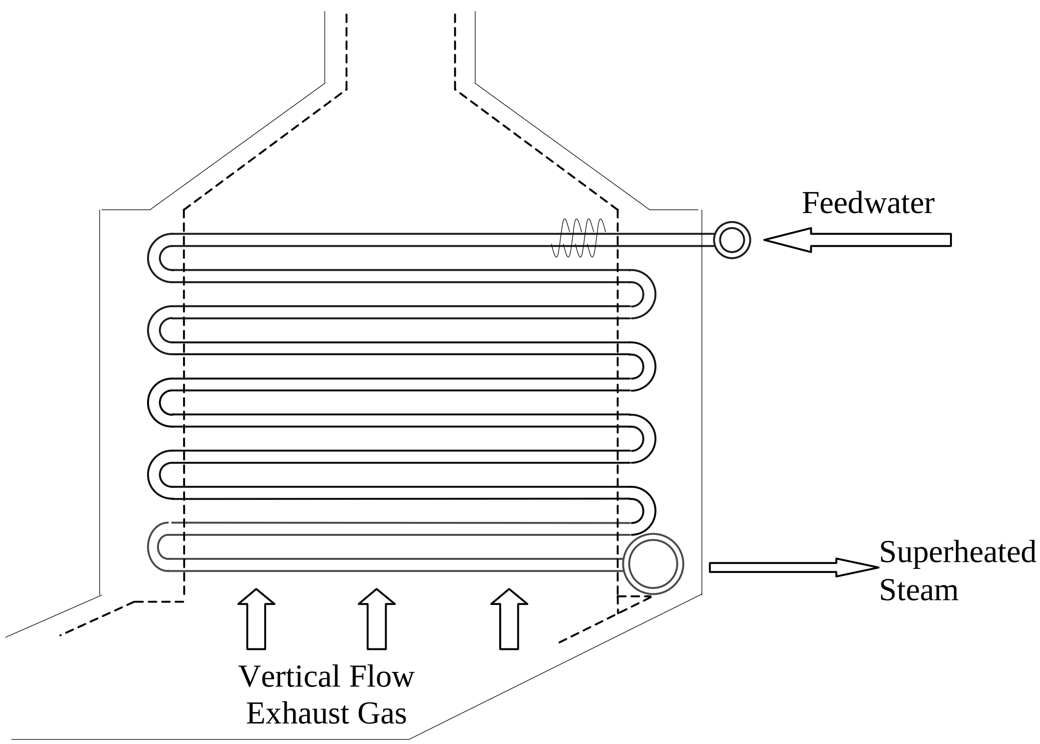


Figure 6. Once Through concept

Brief review of Ruswil Gas Compressor Station Combined Cycle Plant

There are several advantages that the OTSG offers which prompted GE Nuovo Pignone to select this equipment for the Ruswil compressor station. These advantages are addressed in the following pages.

By examining the first IST OTSG installation in Europe, this section will give a brief description of the Ruswil compressor station combined cycle. With small modifications it could be used to describe most of the applications where an OTSG is part of a cycle.

Gas turbines in the power range of 20-50 MW have already accumulated millions of operating hours in combined cycles. GE Nuovo Pignone's PGT 25 two-stage power turbine, probably the most common mechanical drive for the oil and gas market, will be used in Ruswil's compressor station in Switzerland. As claimed by its manufacturer, all their experience gained in the field of heavy duty gas turbines and compressors has been invested in this engine. The best overall performances have been achieved in the range of 12.67 to 23.1 MW, with maximum efficiency above 37%. At 6500 rpm the PGT25 is suitable as a drive for a directly coupled centrifugal compressor. In the mentioned compressor station GE Nuovo Pignone's gas turbines have been driving GE Nuovo Pignone's PCL pipeline compressor.

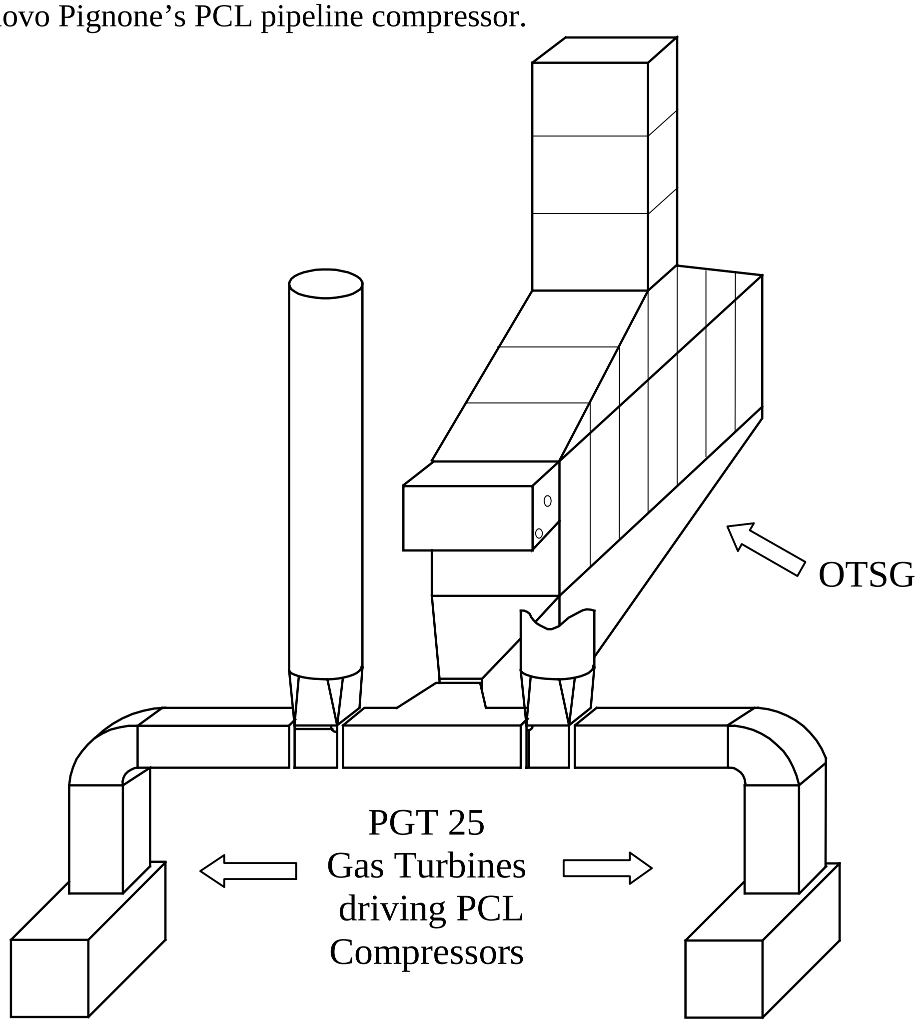


Figure 7. Ducting and OTSG arrangement for Ruswil's gas compressor station

Winning an international tender to build an enhanced combined cycle utilizing waste heat from two compressor drives, GE Nuovo Pignone later rewarded the HRB supply to IST. One major obstacle that the plant designers faced was the location of the existing building. Due to the site layout, the major components could not be placed in a conventional manner. Nuovo's plant designers recognized the OTSG's light weight and small footprint and intelligently positioned the HRB and an air cooled condenser on the roof of the existing building, directly above their two compressors.

Analyses have shown that one reasonably sized HRB would be sufficient to meet the steam demand. The selected steam turbine was sized for around 8.5 kg/s of high pressure (HP) steam at 30 bara and 455 ºC. The steam turbine driven electrical generator will supply power to the national grid. The heat demand from the low pressure (LP) steam loop is constant, regardless of the gas turbine load and the exhaust conditions (which are expected to have wide fluctuations). In order to grant constant heat to the LP tube bundle section, the HP steam flow will be modulated, resulting in a large range of HP turn-down.

The prime user of the LP steam is an external condensing heat exchanger. Its role is to provide heat for a nearby greenhouse. At lower heat demands coming from the greenhouse, the excess LP steam would be fed into the steam turbine. Again, the OTSG's capability to reduce the LP flow to 50% of the designed value enabled Nuovo's designers to size the LP steam turbine feedline for half flow only.

As Figure 7 illustrates, the system is designed so that the OTSG can receive exhaust gas from either of the engines, but from only one at a time. In its 15 years history and after almost a hundred installations around the globe, this was the first application where by-pass stacks were part of the OTSG. The prime duty of the compressor station is to ensure uninterrupted gas transportation. To meet this demand the current configuration requires that each exhaust line be equipped with a diverter valve and a by-pass stack. Despite the presence of by-pass systems, the plant designer wanted the dry-running capability of the HRB to allow additional flexibility in the plant operation.

Relatively long and winding flue gas ducting has resulted in a demand for a small gas pressure drop through the HRSG. The selected longitudinal and transverse pitches in addition to the selected effective finned tube length have resulted in an acceptable pressure drop throughout the OTSG unit for a wide range of exhaust flows.

Overall plant flexibility has been boosted by an attemperator on the HP steam line. This device is rarely seen in combined cycles with an OTSG. The rather simple control system of an OTSG allows quick adjustments of the feedwater flows to get the required steam temperatures. The attemperator has usually been installed in plants where a remarkably short start-up time was required. For Ruswil's plant the HP acts as a regulating loop for the LP steam output and therefore the attemperator is required to control the steam temperature entering the steam turbine.

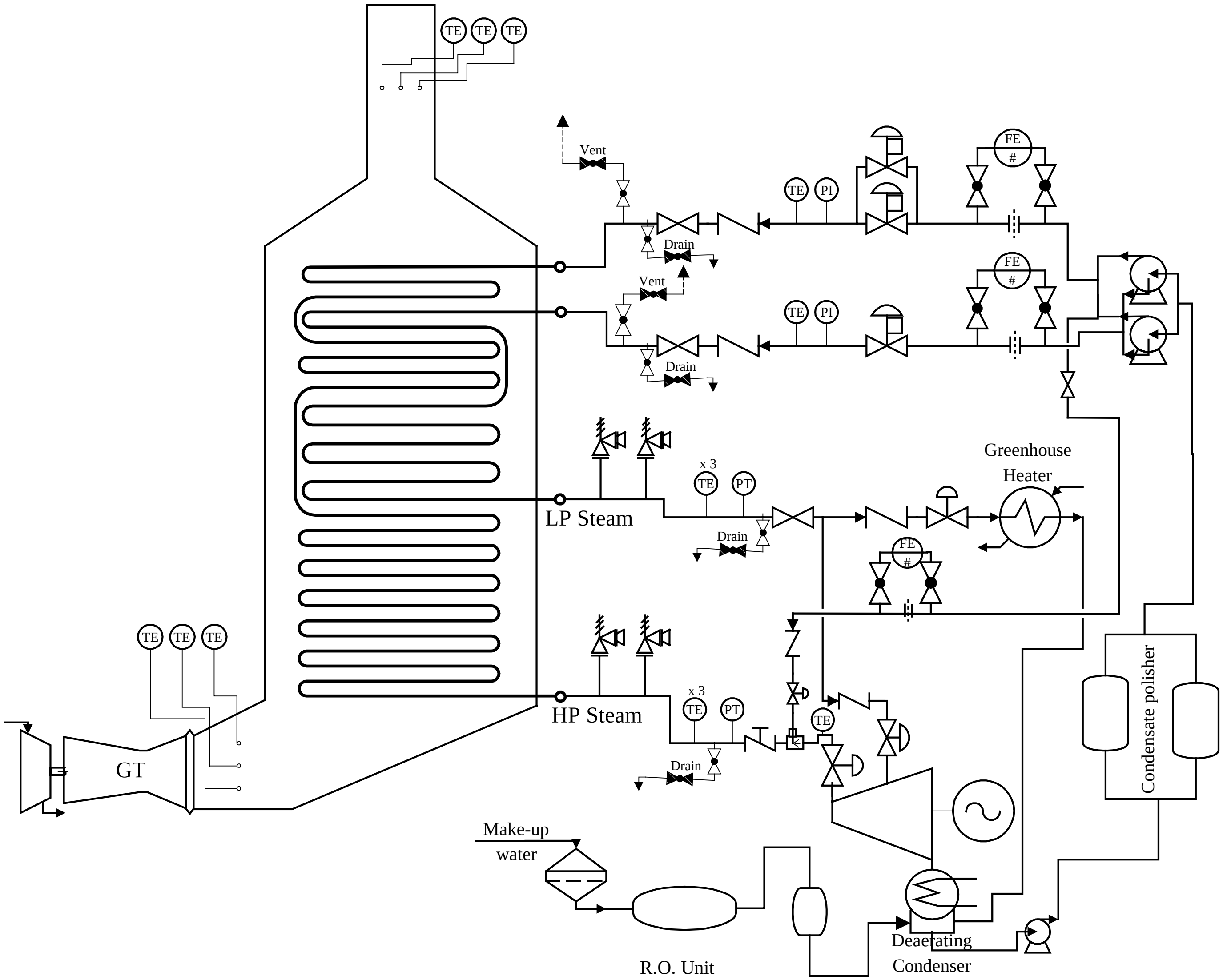
Most of IST's OTSGs operate without conventional pressurized deaerators. The same has been applied to this plant, and as seen in Figure 8, no conventional deaerator has been included in the condensate return line. Alloy 800 tubing, although highly corrosion resistant, could experience stress corrosion cracking if exposed to cold feedwater and sulphur based fuels. The dry running temperature limit has been set at 816 ºC for this alloy. Selection of alloy 825 tubing in the cold end of the unit removes the risk of stress corrosion cracking, but reduces the dry run capability to 538 ºC.

The simplified flowchart for the referenced plant has also been provided on Figure 8.

One of the plant design requirements was a minimal impact to the surrounding environment. Very stringent local noise requirements have been imposed for the extension of this gas compressor station. Despite the fact that the GTs will operate in an enclosed environment, and that the OTSG's noise attenuation properties are considerable, a silencer will be inserted into each exhaust line in order to ensure a very low sound power level at the near and far field distances. The OTSG also minimizes other environmental impacts ordinarily associated with a HRSG. Active water treatment, blowdown, chemical injection, boilout and chemical cleaning are not required for the operation of an OTSG. The feedwater make-up rate for Ruswil's combined cycle plant is expected to be less than 0.1% of the cycle flow. This value has been observed in compressor stations along the Trans Canada pipeline where OTSGs are part of combined cycle plants. This amount of make-up is small enough that it meets the requirement for minimal natural resource usage from the vicinity of the plant.

It should be noted that despite some specifics for this plant, most combined cycle plants with the OTSG have been very similar. An extra steam loop, reheater or preheater may add complexity, but the OTSG concept can easily adapt to any of these combinations.

The equipment erection, including OTSG, is scheduled for late spring of 2001. The commissioning and start-up will take place shortly after.



igure 8. Simplified flowsheet for typical combined cycle with OTSG

The Unique Features and Advantages of the Once Through Steam Generator.

Dry running operation

The OTSG unit has full dry running capabilities without the need of a bypass stack and diverter valve system. All OTSG units are well suited for this type of service due to the material selection within the OTSG unit. A diverter valve, despite manufacturer guarantees, will leak after a small amount of operation time. Over the lifespan of the boiler, the thermal losses corresponding to the gas leak becomes considerable. Operation and maintenance of these, often expensive system, adds to the plant operation complexity, and lowers availability.

As indicated, the OTSG pressure parts are comprised of a high nickel chrome alloy. Alloy 825 is ASME code rated up to 538 degrees ºC while alloy 800 is ASME code rated up to 815 ºC. Dry operation is usually well below these limits and therefore the pressure parts are not limited by dry run operation.

The fins of the OTSG are mostly made of carbon steel. When the unit is run dry there will be a very slow oxidation of the carbon steel fins. This happens at a known rate and is characterized by an oxidation curve. For a normal gas turbine operating temperature it will take over 13000 hours or 1 ½ years to form oxide 0.125 mm thick. The oxidation level caused by normal dry run operation has resulted in a negligible effect on performance. This should provide ample dry operating time for a typical plant life.

Some of IST’s Customers have installed the OTSG and run it dry for up to three months prior to bringing the steam system online. There were no ill effects seen on the boilers as a result.

Reduced weight

Alloy 800 and 825 is a high strength, high temperature, highly corrosion and erosion resistant material that is generally unaffected by the severe water side and gas side environment that can be encountered even when the OTSG is in a dry or non steaming mode. The tube wall thickness typically used provides sufficient extra margin beyond the unit pressure and temperature rating. Today’s market has commercially standardized nominal wall thickness and values often seen in OTSG ranges from 1.2 to 2.1 mm. For comparison, the carbon steel tube wall thickness in similar applications may range from 2.54 to 4.19 mm. Fabrication and handling requirements have set the minimum wall thickness to 1.2 mm even though the pressure rating calculation would allow thinner wall for superalloy tubing. Tubing diameters typically used for an OTSG are 19.05, 25.4 and 31.75 mm. The high strength, small tube diameters and negligible corrosion and erosion allowance have combined their effects and allowed for the use of thinner wall tubing, lowering the OTSG’s overall unit weight.

The once through design assumes no separation between the two phases, and accordingly, no steam drum is required. This significantly reduces water inventory to a range of 1/10 of the total that would be present in a comparable drum-type HRB. Steam purity coming out of an OTSG is determined by feedwater quality entering the unit. There is no requirement for blowdown and the corresponding tank, which further reduces the OTSG’s weight.

Thermal efficiency

Two factors mentioned in the previous section have resulted in a higher thermal efficiency of an OTSG. In the usual case, no heat loss caused by a diverter valve leak is encountered in an OTSG. In order to prevent the buildup of a high concentration of dissolved and suspended solids in systems, a small amount of boiler water, called blowdown, is continuously discarded in typical drum-type HRSGs. This presents a heat loss. The once through design is insensitive to dry-out location and provides operating flexibility that eliminates concerns imposed by fixed geometry and approach temperatures limitations. Provided that at the design point both conventional type HRSGs and OTSGs have the same efficiency, at part loads the OTSG will perform more efficiently.

Simple control, start-up and operation

The OTSG has a simple control system due to the simple water/steam flow path and the elimination of many components required by a typical HRSG. A single point of control is all that is required. Feedwater flow rate is the only control variable. Feedwater is admitted into the boiler at a rate necessary to produce the desired steam temperature or pressure. Since the superheat zone can be anywhere from the first row to the outlet row, a wide range of steam flows, pressures and temperatures can be accommodated for start-up, normal operation and design optimization. The OTSG allows off-design operation because it has, in effect, a variable length superheater. By modulating feedwater flow, the superheated steam’s temperature can be controlled to any specified temperature with 5 ºC tolerance without steam conditioning (attemperation).

The OTSG can be started simultaneously with the start of the gas turbine or, if designed for dry running, after the gas turbine is fully loaded and on-line. The OTSG is normally started hot and dry once the gas turbine has started to ensure the tubes are warm. At an exhaust temperature of about 180 ºC (leaving the OTSG) the feedwater flow rate is ramped up as the gas turbine is loaded (similar to the fuel acceleration control for the gas turbine).

When the OTSG water flow is below approximately 80% of unfired design flow, the OTSG will produce superheated steam at the same temperature as the inlet gas from the gas turbine. When loaded, and the water flow is at 85% to 90% of the rated unfired setpoint for gas turbine operating conditions, the feedwater will go to closed loop control on the superheater temperature feedback. On pressure control, the OTSG can go to a closed loop control at approximately 30% of the unfired steam flow.

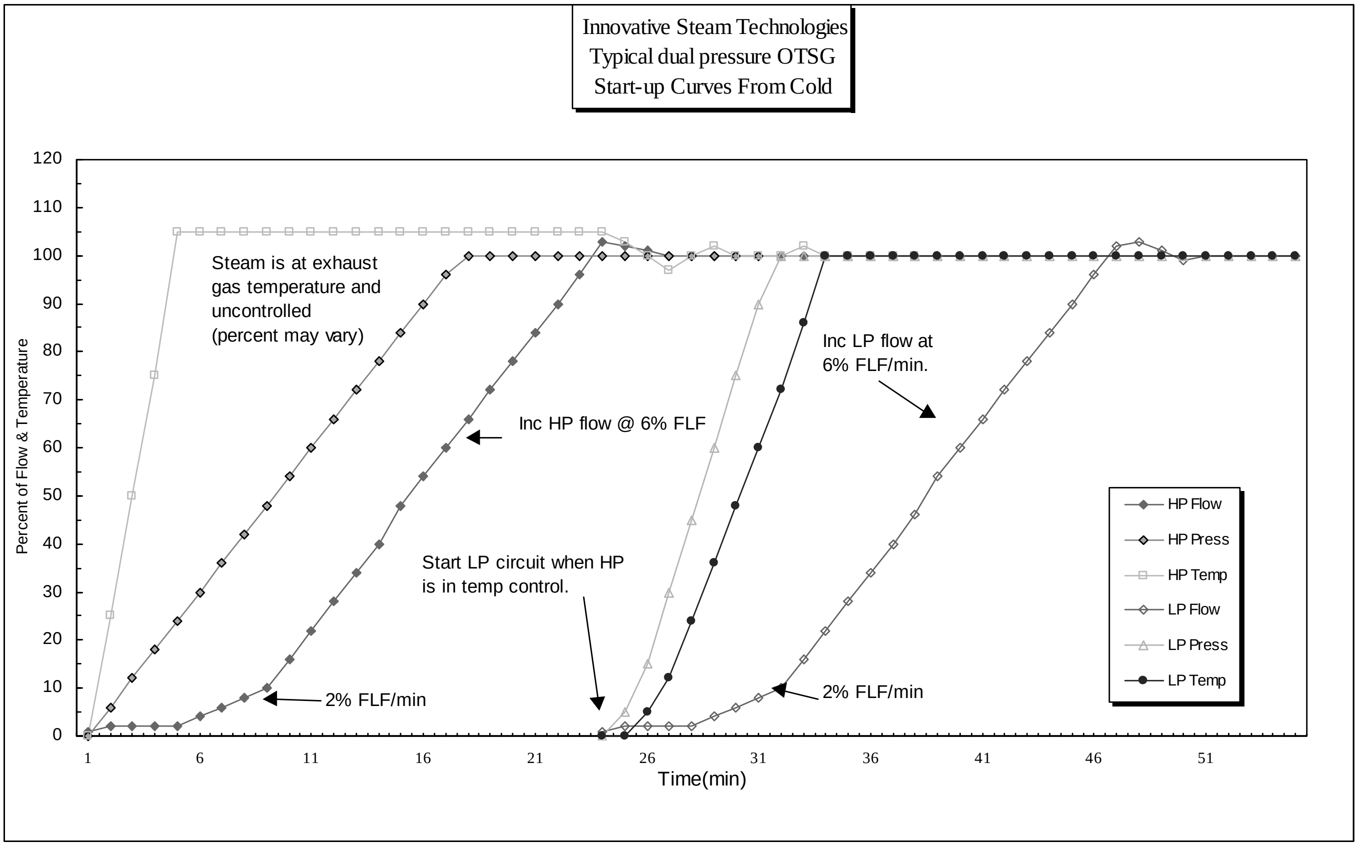


Figure 9. Typical Start-up Curves for a Dual Pressure OTSG coupled to a LM 6000 GT

At steady state conditions, superheat temperature can normally be maintained at ±5 ºC of the set point. Transients are accommodated with a feed-forward control strategy that sets the feedwater flow to a predicted value based on turbine exhaust temperature and flow rate.

The patented approach to controls and the use of microprocessors provides precise and fast transient response across a wide range of operating conditions.

Gas turbines working as a mechanical drive are often exposed to sudden and sometimes sharp changes in their loads and consequently the exhaust conditions. Due to a very small water/steam content and a reduced mass of metal involved in the heat transfer (thin wall tubes with a reduced diameter), an OTSG will quickly respond to these changes. Three thermocouples installed on the steam line feed the DCS with temperature data. Any departure from the set point would trigger a response from the DCS causing the feedwater control valve to make an appropriate corrective action on the feedwater flow.

Figure 9 provides start-up curves for a non-conditioned (no attemperation) HP and LP steam lines at an actual OTSG installation. The HP steam flow is 12.32 kg/s @ 45.16 bara and 399 ºC. The LP steam output 3.20 kg/s @ 7.24 bara and 188 ºC

Modular design

The OTSG system consists of five major components: inlet duct, inlet plenum, OTSG module, exhaust hood and exhaust stack. Each component can be recognized on Figure 7. For supplementary fired units a burner and burner duct are added to the system. Each component is designed for shipment and installation as a single piece within the constraints imposed by shipping weight and size limitations. The prime sizing criteria for ducting is flow velocity.

Each component is internally insulated with three layers of ceramic fiber insulation and lined to provide a cold, gas tight enclosure. The overall insulation thickness ordinarily used is 152 mm. Selection of a different fiber density will result in the outer casing wall temperature of up to 60 ºC for different flue gas temperatures.

Stainless steel liner plates cover the insulation. Since flue gases pass through ducting with considerable velocity, special attention is given to the liner arrangement in respect of gas movement direction and the thermal growth of plates. These plates are made of 3.17 mm stainless steels panels. Scalloped plates, maintaining the constant distance between liner plates and the external casing panels, are welded perpendicular on the external casing panels. Their grid like pattern prevents movement of compressed insulation. Specifically designed to prevent heat transfer from hot liner plates to cold external casing, these plates are made of stainless steels as well.

All of the OTSG modules are delivered to site fully assembled and usually within one day will be joined into one system. Once the inlet duct and plenum are set, the remaining components are simply stacked upon the other, aligned and the I-beam mating joints are seal welded. A connecting surface between components will be filled with insulation and covered with the liner plates fully fabricated for a fast and easy installation.

Module description

The majority of the OTSG units installed accommodate exhaust gas that flows vertically upward and the water flow enters at the top and flows downward through the serpentine tube bundle to exit at the bottom as superheated steam. The OTSG uses specially developed and fabricated finned tubes matched to the operating requirements of the OTSG. The proprietary finned tubing manufacturing process allows many different combinations of fin material to be bonded to the high nickel seamless tubes. This bonding process allows operation of the tubes to temperatures over 815ºC if stainless steel fins are used.

The alloy tube bundle is supported vertically by tubesheets spaced along the unit length. The tube sheets are hung from the top by cross beams mounted on side pads that compensate the structure for differential thermal growth (Figure 10). A thermally matched spreader system adjusts the support beam position to allow compensation for thermal expansion. The tubes are free to slide within the tube sheets, and the tube sheets can flex with the entire bundle. This construction allows a high degree of thermal flexibility and is needed for dry operating capabilities and cyclic duty applications, which is a primary requirement for most combined cycles.

To prevent gas from bypassing the heating surface, seal plates are mounted across the ends of the units between the end wall liner and the first tubesheet. Specifically designed “V” seals are positioned between sidewalls and the tube bundles to keep this space flue gas free and allow sufficient thermal growth.

The feedwater headers are mounted in an enclosure on the outside of the unit. Flexible tubes are provided at the inlet of some sections to allow the contraction of the top row of the pressure circuit, which occurs when introducing water to a hot unit. All steam producing circuits have an orifice for balancing flows. This orifice is positioned downstream of the feedwater header and is located within the same inlet header enclosure.

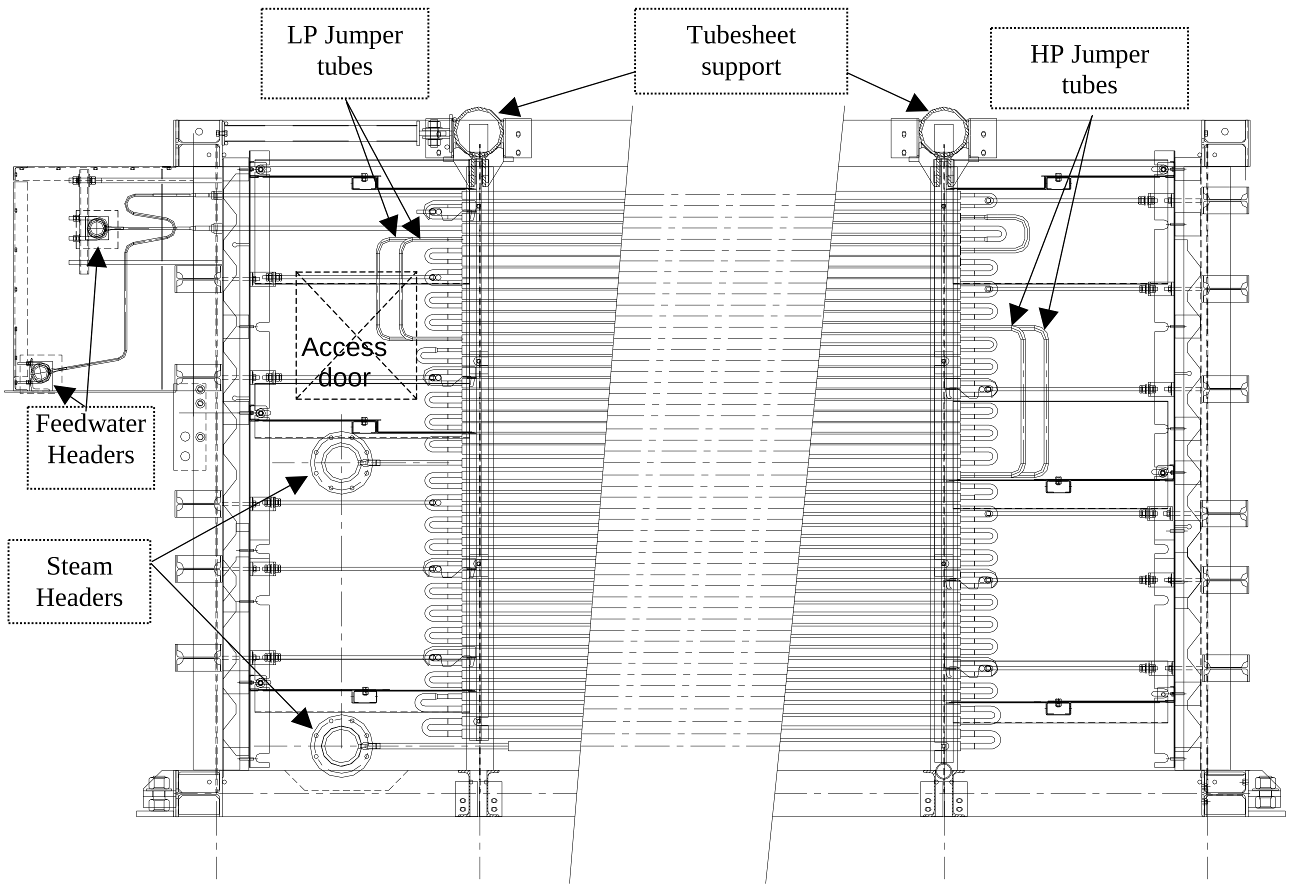


Figure 10. Mechanical Arrangement for a typical dual pressure OTSG

Multiple pressure units are configured by the use of longer u-bends or jumper tubes that allow different pressure level sections of the OTSG to be located in the optimum gas temperature zone for best performance. Since drums and the large amount of interconnecting piping needed on multiple pressure units are not required, the OTSG becomes more cost efficient as the number of pressure levels increase.

Typical OTSGs installed to date are as fully modularized as possible. The OTSG heating surface is usually in a single module with the entire ASME Section I boiler proper components factory welded and code inspected before leaving the factory. A single module OTSG can be shipped in sizes up to about 28,000 square meters (heating surface) to many locations. The single module approach minimizes erection and installation time.

Despite all the complexity and constraints related to installation of combined cycles on off-shore platforms it is worth mentioning an OTSG's particular suitability for this type of application. The corrosion resistance of alloy 825 makes it an unsurpassed material for use in marine environments where the ambient air deposits salts on the heat transfer surface and other boiler components. Rapid corrosion can occur to materials such as carbon steel and low alloys. This effect is amplified when the exhaust gas has a high sulphur content.

In addition to alloy 825's superior corrosion resistance, all or most of the extended heat transfer fin material could be stainless steel. It has also been standard design practice to use stainless steel liners throughout the whole OTSG system. Implementation of 316 series SS liners will reduce the effects of the corrosion due to the salty environment, particularly in the stack where the temperatures are low and acid dew build up is common.

An important factor for an offshore application is maintenance cost. The OTSG simplicity and high quality makes it almost maintenance free.

Conclusion

All the advantages that were mentioned in this paper demonstrate how the OTSG's design makes it suitable for combined cycle application. Furthermore, a gas turbine powering a compressor drive and coupled to an OTSG allows the gas turbine to operate independently of the steam cycle. The OTSG has proven its suitability for heat recovery from engines in the size range typically used in compressor drive applications. By coupling the simple cycle of a gas turbine with a steam cycle the overall thermal efficiency increases and the negative environmental impacts are reduced, particularly with an OTSG.