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Differences Between Once Through Steam Generators and Drum-type HRSGs and their Suitability for Barge Mounted Combined Cycles

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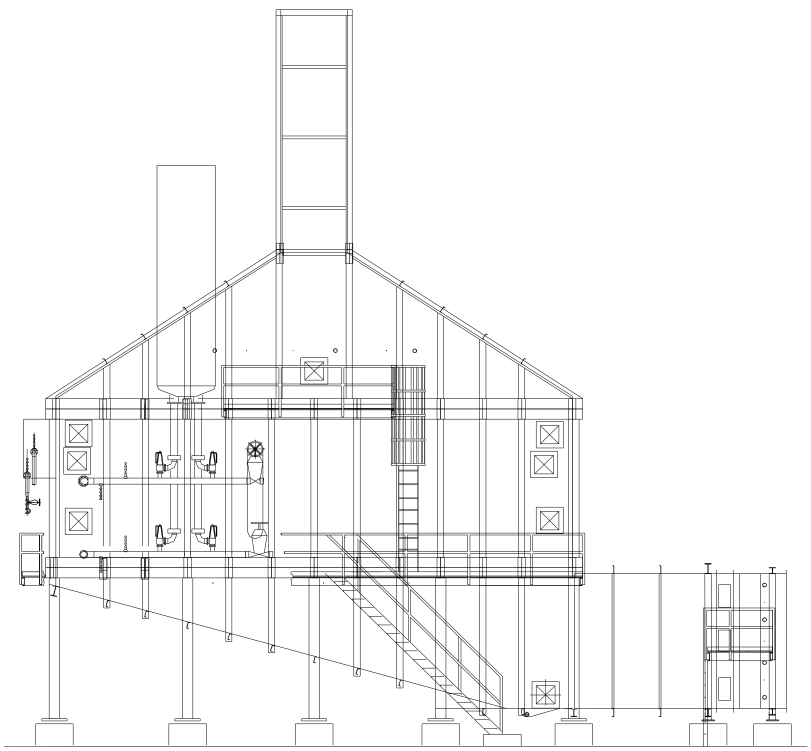

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DIFFERENCES BETWEEN ONCE THROUGH STEAM GENERATORS AND DRUM-TYPE HRSGs AND THEIR SUITABILITY FOR BARGE MOUNTED COMBINED CYCLES

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INTRODUCTION

In the past decade Once Through Heat Recovery Steam Generators (OTSGs) have evolved into a cost competitive and technologically advanced Heat Recovery Steam Generator (HRSG). This is the first new technology to be introduced into the heat recovery field since the wide scale introduction of combined cycles. Over two million operating hours have been accumulated on the units now in service. However, many power plant designers and developers are not aware of the OTSG's superior technology and the many cost, operating and performance advantages that may be obtained when compared with drum boilers. Drum-type HRSGs have many components such as drums, downcomers, separate economizers, generating tubes, separate superheaters, circulation systems and blowdown systems that are unnecessary ancillary components not essential to produce steam efficiently. Water tube drum units were developed to prevent scaling, corrosion and allow control of the steam generating process. With modern materials, control systems, design technology, and water treatment systems these traditional boiler components are costly and not required in a modern combined cycle plant.

The elimination of this equipment and many inherent features have made the OTSG an attractive heat recovery boiler for land based applications. Many of these unique benefits have caused the OTSG to become well suited for marine-based combined cycles, particularly with barge mounted combined cycle power plants.

The power demand, in the fast growing economies of South America, the Caribbean and Asia has fueled the need for a creative alternative that can attract investors and developers. One solution is barge mounted combined cycles power plants. There are some large power projects that are in the development and implementation phases in these regions. However, the large power projects take longer to develop and implement, which causes the supply and demand gap to continue to increase. Power barge projects take less time to develop, design and manufacture and in turn can be implemented faster than the larger projects. Many developers recognize the need for power and have identified combined cycle power barges as the cost effective and timely alternative. Barge mounted Combined Cycles are more attractive than diesel engines or CFBs because combined cycles have lower maintenance cost and requirements, and the units produce more power in a smaller arrangement which reduces the manufacturing and erections time. This paper explores the design, operating and life cycle benefits of the OTSG and HRSG systems and their suitability for barge mounted combined cycles.

OTSG/HRSG DESCRIPTION

The once-through steam generator (OTSG), in its simplest form, is a continuous tube heat exchanger in which preheating, evaporation, and superheating of the feedwater takes place consecutively, see Figure 1. Many tubes are mounted in parallel and are joined by headers thus providing a common inlet for feedwater and a common outlet for steam. Water is forced through the tubes by a boiler feedwater pump, entering the OTSG at the "cold" end. The water changes phase along the circuit and exits as superheated steam at the "hot" or bottom of the unit. Gas flow is in the opposite direction to that of the water flow (counter current flow).

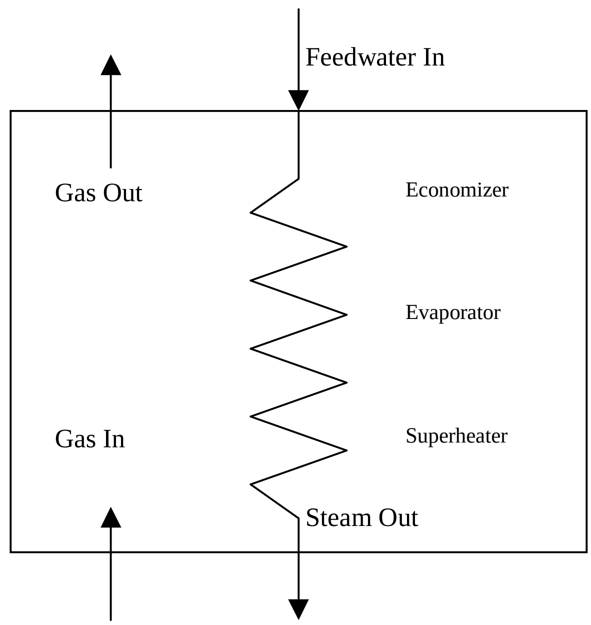

Figure 1. Once Through Steam Generator

Unlike conventional heat recovery steam generators (HRSGs), OTSGs do not have defined economizer, evaporator or superheater sections. The point at which the steam-water interface exists is free to move through the horizontal tube bank depending on the heat input and mass flow rate and pressure of the water. The single point of control for the OTSG is the feedwater control valve; actuation depends on predefined operating conditions that are set through the distributed control system (DCS). The DCS is connected to a feedforward and feedback control loop, which monitor the transients in gas turbine load and outlet steam conditions, respectively. If a transient in gas turbine load is monitored, the feedforward control sets the feedwater flow to a predicted value based on the turbine exhaust temperature, producing steady state superheated steam conditions. Please refer to the Flowsheet Appendix 1. for illustration.

Also unlike conventional HRSGs (Figure #2.), OTSGs do not have steam drums, mud drums or blowdown systems. Water volume is typically one-eight to one-tenth that of a conventional drum-type HRSG. The absence of a blowdown system limits the steam generators thermal losses and lowers the makeup requirements to less than 0.1 percent of the total cycle flow rate, thereby permitting a smaller makeup treatment plant, which is a key factor to consider when evaluating equipment for a barge mounted application.

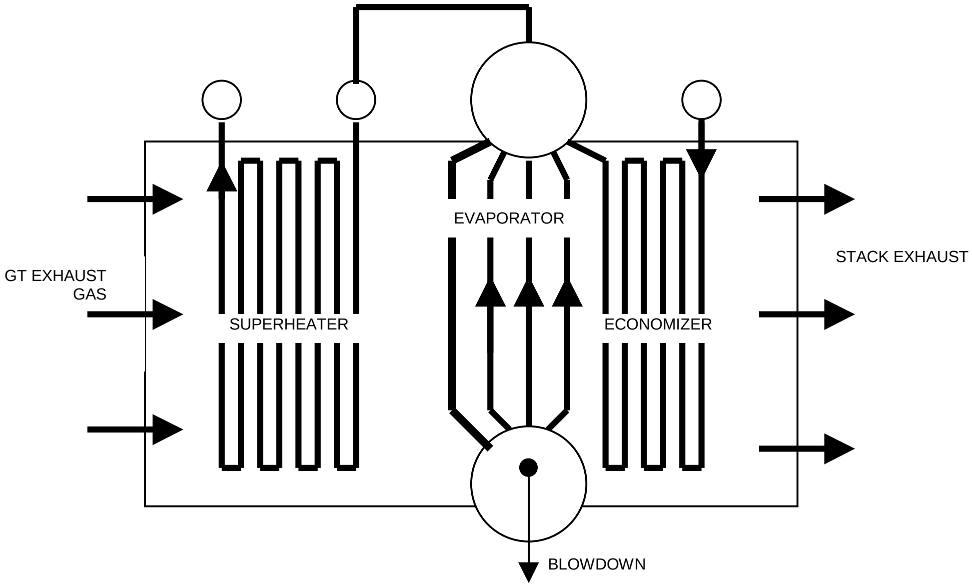

Figure 2. Drum-Type HRSG

Water quality is maintained using conventional deionization and polishing exchange systems, which eliminate deposition into the tube bundle and carryover to the steam turbine. Deionized water treatment systems and condensate polishers are not unique to OTSGs; they are being used with increased frequency on traditional drum-type HRSGs and are favoured for any installation where low life-cycle costs, high reliability, and/or high purity steam is desired.

OTSGs configured for combined cycle or cogeneration operation are typically arranged as vertical flow/horizontal tube systems. The horizontal tube configuration results in a smaller footprint, pushing the units vertically rather than horizontally. Footprint is an important factor to consider when designing HRSGs for barge applications. The major equipment's footprints have a direct impact on the size of the barge required, more so than the weight of the equipment itself. Below you will find a comparison between the overall size of an LM6000 40MW OTSG to that of a comparable LM6000 40MW HRSG. The footprint of the OTSG in the foreground is significantly smaller than that of the HRSG in the background.

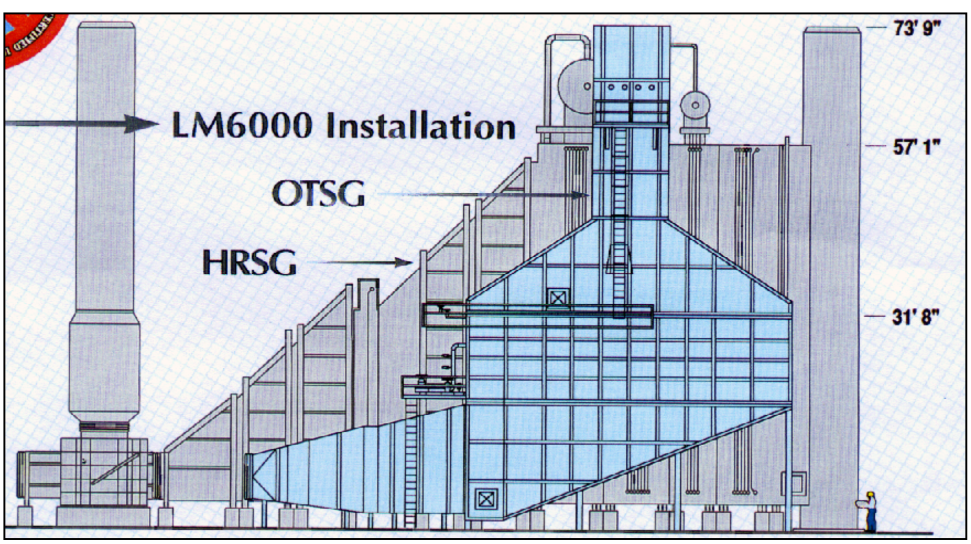

Figure 3. Plan View and Footprint comparison of a LM6000 40MW OTSG to a LM6000 40MW drum-type HRSG. Both units are approximately 5m at their widest point.

Conventional HRSGs use carbon steel as the tube material. Carbon steel loses strength at elevated temperatures, however, making bypass stacks and diverter valves necessary to prevent the hot exhaust from damaging the tubes during dry running conditions. The use of high-nickel Incoloy 800 and 825 alloy tube material, which maintains a substantial fraction of its strength and corrosion resistance at high temperatures, permits full dry running without the need for a bypass stack or diverter valve. Incoloy tube material also limits the OTSG's oxygen sensitivity, avoiding the need for active chemical water treatment. The elimination of the bypass stack and diverter valve, together with the system's modular design, causes the OTSG to be up to 60 percent smaller and lighter than a comparable HRSG, making the OTSG suitable for projects that have size and weight restrictions, such as power barges and marine applications.

The elimination of the bypass equipment reduces the footprint requirement for the OTSG and in turn reducing the size of the barge. This area can be equated to a substantial capital cost savings especially if there are numerous heat recover boilers to be located on one vessel. In addition, the capital cost of the diverter valve and the bypass stack makes the entire system that much more attractive. Figure 3. illustrates that there will be a reduction of approximately 6m x 5m of deck space that would otherwise be occupied by the OTSG/HRSG.

Figure 4. shows a typical OTSG steam/water flow path. Feedwater is metered into the first rows of tubes on the OTSG's exhaust gas outlet end. Water and steam are directed by U-bends at each row to the hot inlet gas in a counter flow path until it reaches the desired superheat temperature and is collected in a header and directed to the steam turbine. Water is heated, evaporated and superheated in one continuous flow path within each of the many parallel circuits. Any orientation can be configured, since gravity forces are not used in the design. Water flow can be down with exhaust gases vertically upwards, or it can be horizontal gas flow with vertical tubes, or horizontal gas flow with horizontal tubes. All of these configurations have been extensively tested and installed.

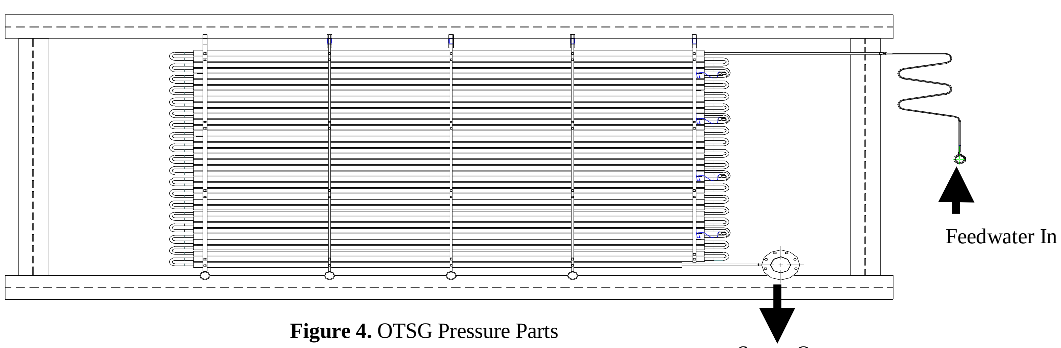

Figure 4. OTSG Pressure Parts

The ductwork for an OTSG system can be manipulated in a fashion to allow the OTSG units to be located directly above the gas turbines, particularly for gas turbines that exhaust vertically.

Configuring the GT and the heat recovery boiler in a "bunk bed" configuration can reduce the deck area requirements by +30%. In addition, both HRSG and OTSG systems can easily accommodate elbow duct configurations, which also helps reduce the total deck space requirement. Appendix B. contains general arrangements with these styles of configurations. This approach is also being used on offshore production facilities.

MECHANICAL DESIGN CHARACTERISTICS OF THE OTSG SYSTEM

The OTSG uses specially developed and fabricated finned tubes matched to the operating requirements of the OTSG. Most of the 50 OTSG units in operation to date have a requirement for dry operation at full gas turbine power. As discussed, the tubes are made of high nickel alloy capable of exposure to high temperatures as per Section I of the ASME Boiler Code. Dry operation with most current gas turbines allows the use of carbon steel fins, which are currently installed on many OTSGs for the most cost-effective heat transfer surfaces; stainless steel fins are employed when the ambient conditions are severe. The high nickel stainless steel tubes permits the use of passive water treatment (PWT) with the OTSG. The proprietary finned tubing manufacturing process allows many different combinations of fin material to be bonded to the high nickel seamless/welded tubes. This bonding process allows operation of the tubes to temperatures over 1500ºF if stainless steel fins are used. For most applications carbon steel fins are optimum but stainless steel fins have been operated to high temperatures or installed in cold economizer rows without feedheating to improve performance while minimizing corrosion caused by water condensation.

HRSGs are susceptible to the cold end problems in the preheater rows of the boilers. These problems include corrosion or stress corrosion cracking of the carbon steel or stainless steel heat exchanger tubes and corrosion of the carbon steel fins due to operations below the acid dew point. These problems are amplified when the turbine fuel contains a high sulfur content, which is a primary fuel in developing countries, where barge mounted applications are most attractive. In order to avoid these types of cold end problems, HRSGs are designed to accommodate slightly higher stack temperatures and higher feedwater temperatures, which, in turn, can reduces the overall plant efficiency. OTSG systems employ alloy 825 and stainless steel fins in the inlet rows (economizer) of all the pressure levels and a preheater is not required. These materials minimize the effects of corrosion; therefore the OTSG systems accommodate lower feedwater and stack temperatures. Some OTSGs systems with Sulfur Fuels have accommodated feedwater temperatures lower than 60ºF, which helps lower stack temperatures.

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. Every few feet flexible tube sheets support the bundle. The tube sheets are hung from the top by cross beams mounted on side pads that compensate the structure for differential thermal growth (Figure 5). 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 barge mounted combined cycles.

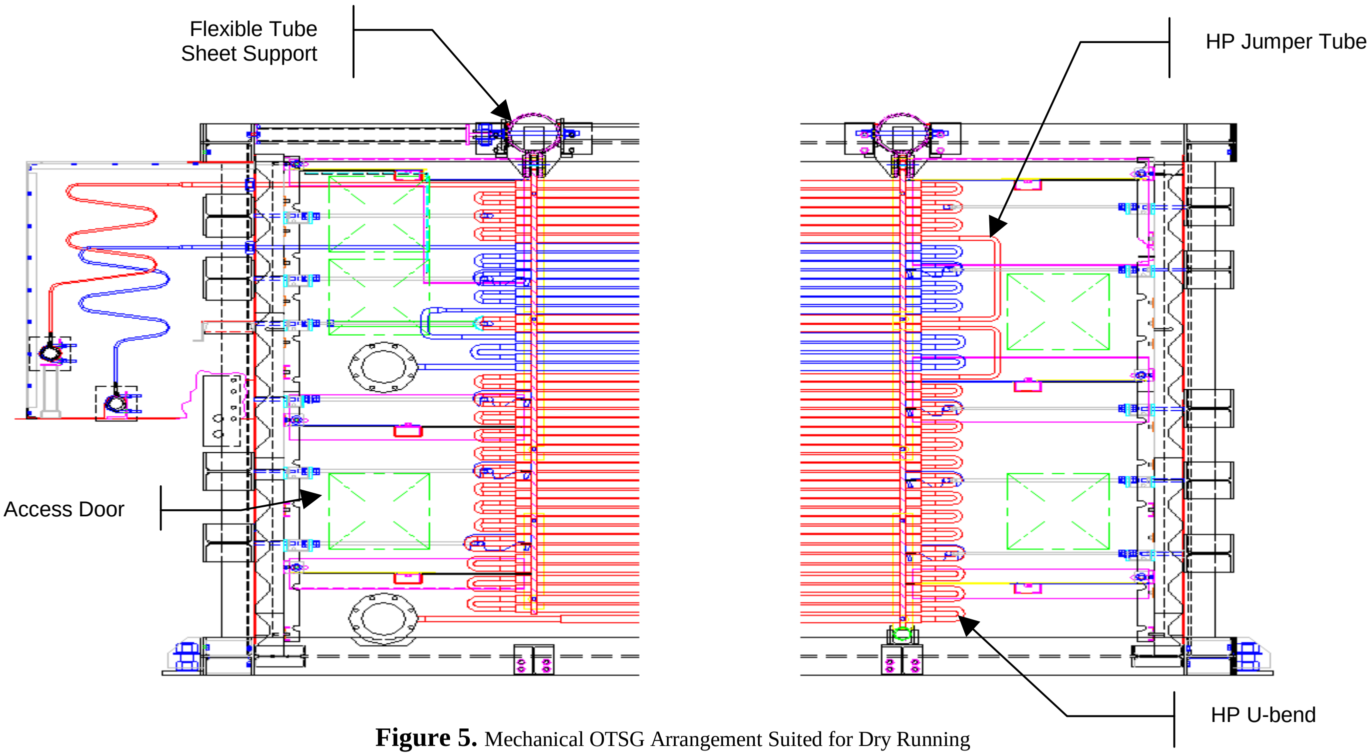

Figure 5. Mechanical OTSG Arrangement Suited for Dry Running

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. Figure 5. illustrates a typical arrangement of u-bends and jumper tubes. 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.

OTSGs installed to date are fully modularized. The OTSG 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 30,000 square meters to many locations. The single module approach minimizes erection and installation time and cost. This reduces the project's gestation period and causes the barge mounted combined cycles to become increasingly more attractive to developers and financiers of these power generating facilities.

ENVIRONMENTAL CONSIDERATIONS

The are numerous environmental factors that must be considered when designing OTSGs/HRSGs for marine applications. These factors have a direct impact on the plant performance, maintainability and the cost of the equipment.

The main design impact is due to the marine environment, particularly the salts in the air. The ambient air contains salts that can be deposited on the heat transfer surfaces, heat exchanger tubes and the liner plates of the interior of the heat recovery boilers. The salts can form sodium chlorides, which, when in contact with certain metals can cause significant and rapid corrosion. This is especially true while the HRSG is bypassed or not in service. Under a bypass or out of service scenario, the drum-type HRSG has the potential of having moisture build up on the tubes and the potential for accelerated corrosion of the heat exchanger tubes. Materials such as, carbon steel, low Alloys, and COR-TEN are susceptible to corrosion failures in these environments; and these corrosion effects are amplified when the exhaust gas contains high sulfur content. These materials are common with many drum-type HRSG systems.

Figure 6. OTSG Alloy 825 Heat Exchanger tubes and Stainless Steel Finns

When designing heat recovery boilers for marine applications some design improvements have to be implemented. For instance, OTSGs systems designed for combined cycle applications in or near marine environments are outfitted with suitable material to resist the ambient conditions. Barge mounted OTSGs employ alloy 825 as the heat exchanger tubes throughout the entire tube bundle. This material is more costly, due to the high nickel content, than carbon steel or a T22, however this material is well suited and more resistant to these corrosion effects. The alloy 825 has a high resistance to acids such as: sulfuric, phosphoric, hydrochloric, organic, and a suitability for a sea water environment.

In addition, some of the extended heat transfer fin material would be stainless steel, again, which is better suited for conditions where sodium chloride attack or stress corrosion cracking may be present. The interior liner plates of HRSG systems are typically CorTen or alloy. This material is not suited as a primary liner plate for heat recovery boilers in this ambient condition. As with the OTSG systems, upgrading of the liner plates to a 409SS or 316SS through out will reduce the effects of the corrosion due to the environment.

Any heat recovery boiler mounted on a vessel, like a barge are continuously exposed to pitch and roll accelerations of the deck structure, which is due to wave action. These accelerations are similar, but often not as severe as ground accelerations due to seismic loads.

Therefore, the mechanical design of the heat recovery boilers must be structurally suited for their expected live loading. The OTSG system is inherently designed in a fashion that the pitch and roll movements are not a major concern. The tube bundle of the OTSG is restrained in a proprietary fashion that reduces the impact of these movements on the tube bundle and headers. During the OTSGs development in the 1980s, the equipment was extensively tested for combined cycle applications on military vessels under severe conditions. In addition, the OTSG performance is not gravity dependent, while HRSG performance is a function of gravity and drum level control. Roll and pitch action on a steam drum may cause the drum level to produce a false reading and trip the steam cycle.

These loads and movements can be avoided or reduced by mooring the vessels in a sheltered lagoon or harbour and restraining the horizontal movements with dolphins. Or a location can be selected near a harbour or river, excavated and then the vessel can be towed into the excavated location and back-filled and fixed. Ideally the vessels will always be built in a location, such as a shipyard [possible in a different country] and then towed to the site of operation. Therefore, there will always have to be some considerations due to roll and pitch accelerations.

One of the factors that support barge mounted combined cycles is the ability to design plants [including Heat Recovery Boilers] to minimize maintenance cost. Maintenance cost can escalate when these types of plants are located far from the Original Equipment Manufacture's (OEM) support centres. Therefore, increasing the project's capital cost, marginally, for design improvements, such as those mentioned above, can be justified because the design benefits can reduce the project's life cycle and maintenance cost significantly.

WATER CHEMISTRY REQUIREMENTS

The high nickel stainless steel tubing is of small diameter and thin walls. Water solids are removed externally and not in the steam generator, and no chemicals are needed for the OTSG. Oxygen removal is also unnecessary and typical control of feedwater chemistry and drum chemistry is not used in operating OTSGs. Only a simple conductivity transducer is used to monitor the OTSG's feedwater total dissolved solids (TDS) levels of less than 50ppb or less than a cation conductivity of 0.25 micro-mhos/cm. In a power plant application (no steam loss to process) a 0.1% or less makeup is commonly experienced (no blowdown required as with drum – type HRSGs) and exchange D.I. beds for make-up and full flow polishing is often the most cost effective solution. For cogeneration where makeup can be higher, some systems use reverse osmosis and exchange beds or regenerative D.I. systems. OTSGs with the highest operating time have full flow feedwater polishing exchange beds that last about 3 years before exchange is required, which can be an added benefit for reducing maintenance requirements on barge applications. HRSGs traditionally have make up rates of 2.5% or higher in combined cycle applications. The 2.5% percent makeup is due to blowdown and steam losses through the system. The blowdown must be disposed of, and in some cases blowdown treatment is a requirement. Therefore, additional disposal equipment would be required, and the plant would have a thermal loss due to the blowdown.

Consistent management of water and steam side chemistry is essential for long term reliability and durability of the HRSG. High pressure boilers are very unforgiving of even isolated major chemistry excursions. The thin wall tubes used in both HRSGs and OTSGs leave no practical corrosion margin for even occasional chemistry excursions[1].

Post construction chemical cleaning of water side components and steam purge of steam pipes is extremely important to long term durability of HRSGs. Many HRSGs, which were not thoroughly cleaned, have suffered corrosion from failure to completely drain while shutdown due to clogging of maintenance drains[1]. This problem is not experience with OTSGs systems. As explained above, the OTSG has polished feedwater entering the unit and in turn clean steam leaving the unit. The OTSG does not contain or add any impurities to the system and the unit arrives with 100% of the pressure parts completed and sealed in a clean state. In addition, any water that is contained within the tube bundle during a shutdown scenario will completely boil dry due to the residual heat contained within the fully insulated unit. This feature will increase the plant's operability and reduce the maintenance requirements that would have otherwise been encountered if an HRSGs were used.

HRSG systems require elevated thermal deaerators to reduce the dissolved oxygen in the water/steam. This is a requirement because of the carbon steel tubes and drums in the unit. The alloy 800 and alloy 825 tube material commonly used in OTSG systems are not oxygen sensitive, therefore the OTSG does not require deaeration to the same extent as the HRSG steam plants.

Often there is carbon steel piping within the steam plants of combined cycles featuring OTSGs as the heat recovery boiler. Therefore, it is advisable that deaeration be used, and a vacuum deaerator may be the most practical alternative. A vacuum deaerator's physical size is smaller and the cost is often less. The vacuum deaerator also uses less steam than a tradition pressurized deaerator which could otherwise be contributed to the plant balance and improve the cycle efficiency. Vacuum deaerators cause lower feedwater temperatures, however low feedwater and stack temperatures do not promote corrosion problems for OTSGs in the cold economizer end.

OTSG vs. HRSG OPERATION

The OTSG's have no steam or water drums or blowdown systems. All feedwater entering the OTSG is converted to steam. During start-up, steam production will begin shortly after admission of feedwater into the OTSG. By starting steam production as soon as the temperature of the exhaust gas exiting the OTSG has reached a minimum required value, the thermal shock factor is reduced and the life of the OTSG will be maximized.

As water is first admitted to the OTSG, the steam being produced will be very near the exhaust gas temperature at the inlet to the OTSG. The steam temperature can only be controlled when the steam production has reached unfired full load unless a downstream attemperator is used. Once this point is reached, varying the feedwater flow rate into the OTSG controls steam temperature. Increasing feedwater flow will decrease outlet temperature and vice versa.

During start-up, the steam temperature may be higher than permitted to the inlet of the steam process (depending on steam process and gas turbine design). Therefore, the steam plant must be designed to allow the steam produced from the OTSG to be temperature regulated before admission to the plant steam piping system.

There are constraints on the ramp rates for the start of steam production on the OTSG's. In addition, there are constraints on the steam output pressure transients. In particular, rapid pressure transients must be avoided. Rapid pressure reductions can cause the water in the OTSG tubes to swell in sections where the water has not been fully evaporated. This may result in water being swept along into downstream tubing in the higher temperature zones creating a risk of tube failure. The ramp rates for OTSG systems are considerably faster than drum-type HRSG systems, typically in the order of magnitude of 1/3 the time. The OTSG contains significantly less water than a drum type unit and in fact the OTSG is started dry, therefore the unit does not have to wait until the large volumes of water contained within drum units heats and begins to evaporate. This causes the OTSG to be ideally suited for combined cycle applications where cycling or daily start-up and shutdowns are required. The cyclic load does not mechanically effect the OTSG since all the tubes and headers are relatively thin walled which means that the material is geometrically stronger than HRSGs under these loading scenarios. Figure 7. contains a typical start-up curve for a dual pressure OTSG system coupled to a 40MW LM6000 gas turbine.

Since all feedwater entering the OTSG is converted to steam, the feedwater must be of the highest quality to ensure that no scaling occurs inside the tubing and that the purity of the steam output is suitable for the process. To minimise the risk of problems with the OTSG, pH and conductivity must be continuously controlled and monitored to confirm that the water quality is always within the specification.

It is important that steam de-superheating stations are operating properly. Failure to maintain proper downstream conditions could result in equipment damage if required operating conditions are exceeded. As a point for operating consideration, excessive venting of steam from the OTSG will require high make-up rates, placing greater demand on the demineralization and chemistry control equipment. These combined effects will result in reduced plant efficiency, increased chemical consumption and accelerated exhaustion of demineralization units.

The OTSG does not have the steam accumulation ability to the same extent as a drum-type HRSG system. When the steam side of a drum plant is trip, the drums contain residue steam for a longer period than the small diameter tubes of the OTSG. Though the small diameter tubes and low water content do contribute to the boiler's response time and performance, the small diameter tubes create a large water side pressure drop which must be accounted for in the project evaluation. Essentially, the feedwater pumps are sized larger than drum units and the auxiliary power consumption increases. This marginal increase in capital and operational cost can easily be offset by the elimination of the bypass stack.

OTSG DESCRIPTION - CONTROLS

The OTSG has a simple control system due to simplification of the water/steam flow path and elimination of many components required for a typical HRSG. A single point of control is all that is needed. Feedwater flow rate is the only control variable. Feedwater is regulated at the rate necessary to produce the desired steam temperature. Since the water level 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 traditional drum-type HRSG has a fixed geometry superheater that cannot accommodate wide operational changes without multiple desuperheaters being employed. The OTSG allows off-design operation because in effect, it has a variable length superheater.

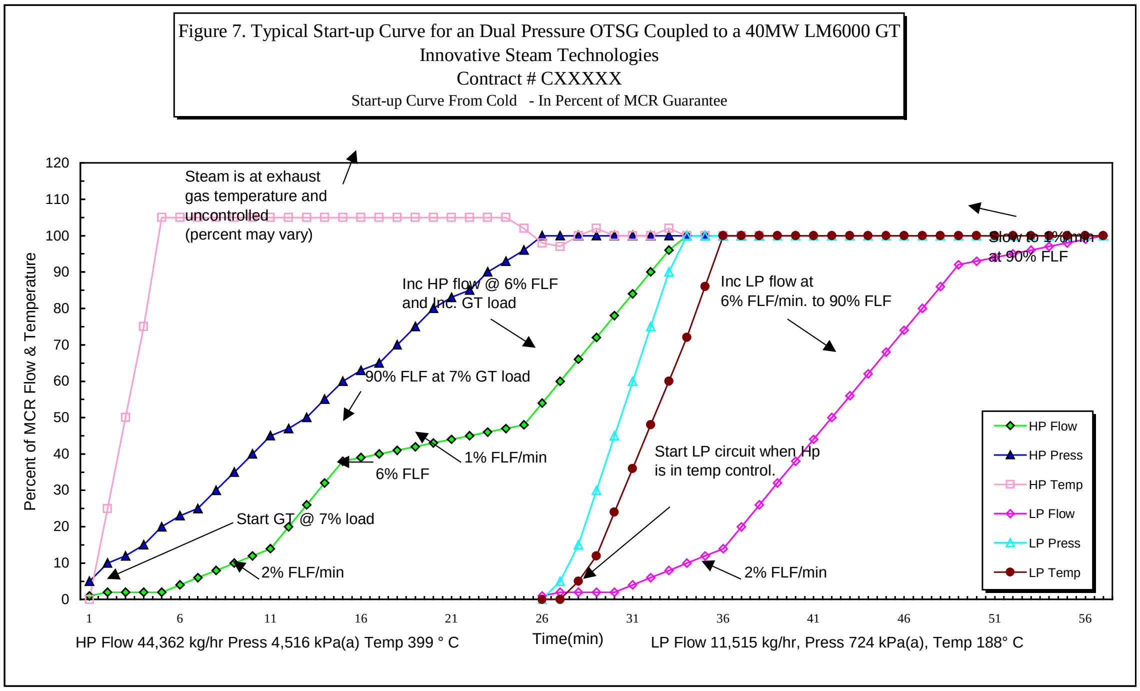

Figure 7. Typical Start-up Curve for an Dual Pressure OTSG Coupled to a 40MW LM6000 GT
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Start-up Curve From Cold - In Percent of MCR Guarantee

At the operator's preference, the OTSG can be started simultaneously with the start of the gas turbine, or, after the gas turbine is fully loaded and on-line. The OTSG is normally started hot and dry once the gas turbine has started. This is to ensure the tubes are hot. At an exhaust temperature of about 300ºF (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 hot starts are used and water flow is below approximately 93% of 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 set point for gas turbine operating conditions, the feedwater will go to closed loop control on superheater temperature feedback (refer to Figure 7). At steady state conditions, superheat temperature can normally be maintained at ±5ºF of a set point or an approach temperature. 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. The OTSG has demonstrated reliable operation without difficulty, with the most demanding transients that can be required of gas turbines.

This "self operating" feature is a critical benefit for barge mounted applications. Operating costs are typically as high or higher for barge mounted plants. Combined cycle plants using OTSGs usually require 50% less operator engineers and maintenance technicians than a comparable drum-type HRSG plant. This is due to the OTSGs ability to operate itself, via the feedforward and feedback control loop. Some combined cycle plants installed in Canada and Australia operate unattended in the evening shift or remotely from distance control stations. This may not be a practical alternative for a barge combined cycle plant, however it demonstrates the ease of operation of the OTSG system over that of a drum-type HRSG.

HEAT RECOVERY BOILER MAINTENANCE REQUIREMENTS

HRSG system maintenance is significant due to the complexity of the interconnecting piping, valves, transducers, control connections, etc. OTSG maintenance is typically performed during scheduled GT shutdowns. The maintenance requirements are very limited due to the inherent design benefits of the OTSG system. Appendix A. illustrates the simplicity of the flowsheet and instrumentation required to control and operate the unit. The amount of instrumentation is significantly less compared to a drum-type HRSG, which translates to significant maintenance savings. The OTSG, itself, does not have any moving parts, essentially it is a large heat exchanger. The ancillary equipment, such as safety valves, control valves, and attemperators have scheduled maintenance requirements as dictated by the equipment vendor, but again, the amount of equipment is reduced with an OTSG system.

The OTSG system does not require soot blowers, even with liquid fuels. Design considerations would be made if Naphtha or a #2 Oil were to be used as the primary fuel for the gas turbine or supplementary firing system. The fin pitch for natural gas units is typically 8-9 fins/in, however when the primary fuel is a liquid fuel the fin pitch would decrease to 5-6 fins/in (Figure 8). This design consideration prevents clogging of the fin spaces and promotes the prolonged efficiency of the unit. In addition, any carbon based constituents that deposit on the fins or heat exchanger tubes can be "baked off" during a dry running scenario. Many HRSG systems that are designed for heavier fuels have no alternative but to soot blow the tube bundle which reduces the availability of the unit and makes for a cumbersome maintenance requirement, which must be avoided on barge applications.

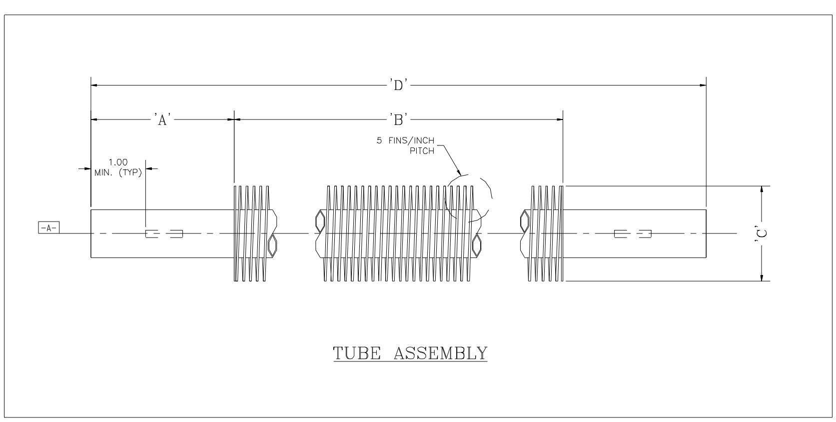


Figure 8. Fin Pitch Illustration

During a scheduled GT shutdown the internal tube bundle of the OTSG can be visually inspected for possible damage, leaks or other maintenance requirements. 100% of the u-bends, jumper tubes and headers are located in maintenance cavities, which have access via maintenance doors, at both ends of the unit (Figure 5). If a tube leak is present, the single circuit can be taken out of service within a few hours and the tube repair could be completed when the schedule permits. The majority of OTSGs have approximately 50 circuits of tubes in each module, therefore, if one circuit is lost in the unlikely event of a tube rupture or weld failure, the circuit would be manually blanked off and the performance would be degraded by less than 1%.

ERECTION BENEFITS

There is a significant potential saving if the installation cost of the heat recovery boilers can be lowered. Most OTSGs are designed in five modules: inlet duct, plenum, steam generator module, hood and stack (refer to Appendix C). Each of the five modules is shop fabricated and can be delivered to the point of erection by rail, road or ocean vessel. The modular design and manufacturing facilitates rapid construction and minimizes crane and work-hour requirements at the erection sites. The OTSGs can be set in position within one day following the placement of the plenum to the barge. Once the plenum is set, the steam generator module, hood and stack are simply placed on top of each other and then seal welded. Additional time is required for completing the module joints and for external piping and commissioning.

The erection cost and duration of many combined cycles is often under estimated making the initial project evaluation in valid. The installation cost is a significant portion of the overall project cost; therefore it is essential that combined cycles be evaluated on an installed basis. The installation savings of an OTSG are the single most beneficial cost savings within a project. The duration of a typical LM6000 sized OTSG takes approximately 3 weeks to complete, and is approximately 25% the cost of a drum type HRSG. Therefore, these costs must be equated in to the evaluation, and the potential cost savings would offset the cost of the polishing system and alloy material.

SUMMARY OF OTSG BARGE MOUNTED DESIGN BENEFITS

The OTSG has many notable features, which demonstrates a significant improvement over the natural circulation drum-type units. It offers high availability, proven experience, and cost savings benefits.

Many of these features were addressed above. The following points are factors that must be evaluated when comparing the suitability of drum-type HRSGs to OTSG systems. The OTSG system's benefits are best represented, economically, when the units are evaluated on an installed basis while considering life-cycle cost.

- *Low Weight, Size and Simple Erection:* The lack of drums and the modular design and manufacture of the OTSG facilitates easy and rapid shipment and erection of the unit. The unit is made up of approximately five modules; inlet duct, plenum, steam generator module, hood and the stack, which reduces erection time and limits the crane requirements. The five modules and the fact that the OTSG uses small diameter tubes makes for a rather light weight and compact design that is definitely suited for projects that have weight and size restrictions, such as on power barges or oil platforms.

• *Resistant to Every Environment:* The outer casing of the OTSG is carbon steel, which is coated with an industrial primer prior to shipment and then painted after erection to prevent corrosion. The inner casing is a 304 or 409 Stainless Steel and the heat transfer tubes are Incoloy 800 and 825 Alloy with an approximate nickel content of +30%, therefore it is unlikely that the casing or the tubes would be sensitive to any environment.

• *Suited for Dry Running:* The OTSG is capable of full dry running without the need for a bypass stack or damper system. The OTSG is capable of this because the nickel alloy tube material maintains much of its strength at high temperature. The elimination of the bypass stack and damper system also contributes to the reduced size of the OTSG.

• *Fast Response:* The OTSG's operation is regulated by a distributed control system that is design to maintain a constant set point in steam condition. The distributed control system controls the actuation of the feedwater control valves (the single point of control of the boiler).

• *Remote Attended Operation:* The simply design makes the OTSG easy to operate and control. The OTSG has a small volume of high pressure, saturated water which makes the boiler inherently safe.

• *High Availability and Low Maintenance:* The 50 OTSGs installed to date have been in operation worldwide for up to over 14 years. The OTSG has no spare parts and significantly fewer controls and instrumentation than a comparable drum type boiler.

OSTG vs. HRSG PROJECT EVALUATION

In a system designed for a drum boiler the OTSG unit can often be comparatively evaluated and selected as best for the plant. However the greatest cost and operational advantages are achieved by integrating the OTSG into the power plant's system at the conceptual plant design phase. In some applications, such as barge mounted combined cycles, steam injection or steam cooling for peaking turbines the OTSG may be the only technically feasible approach.

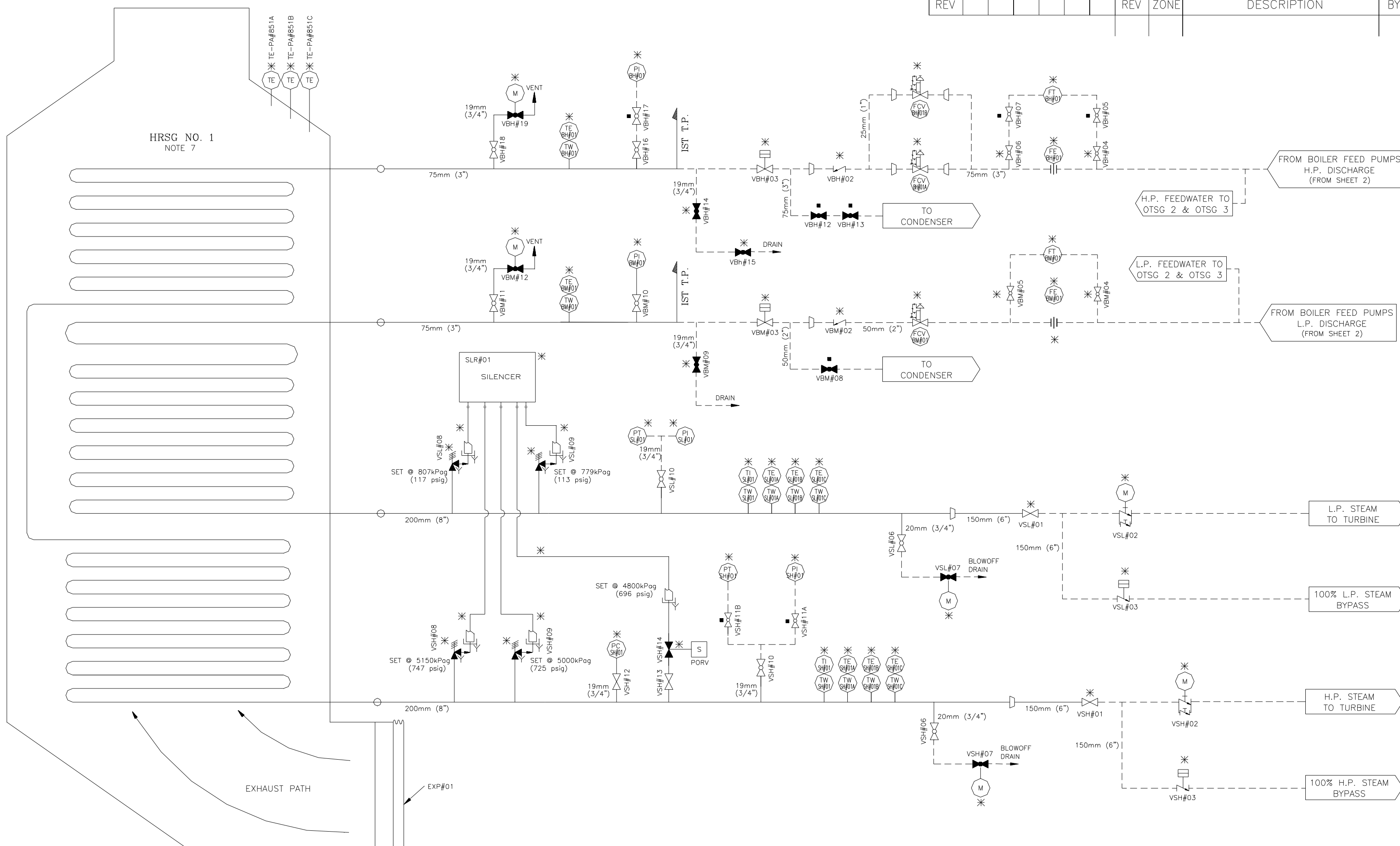
Appendix D. contains a generic evaluation of a drum-type HRSG and OTSG system coupled to a 4 X 40MW LM6000 gas turbines. The evaluation is based on the installation of the units on a combined cycle barge and the values are estimated based on the best available data and should be used only as a guide.

REFERENCES:
[1]M.Pearson, R. Anderson, "Reliability and Durability from Large HRSGs"
"GTCC Design Forges Ahead", Power Engineering International, September 1998
M. Brady, "Once Through Steam Generators Power Remote Sites", Power Engineering, June 1998
T. Duffy, "Once Through Heat Recovery Steam Generators Evaluation Criteria for Combined Cycles", POWER-Gen NA, 1995

Appendix A.

Dual Pressure OTSG Flowsheet

SHT	1	2	3	4	5	6	REVISIONS					
REV							REV	ZONE	DESCRIPTION	BY	APP	DATE



NOTE:

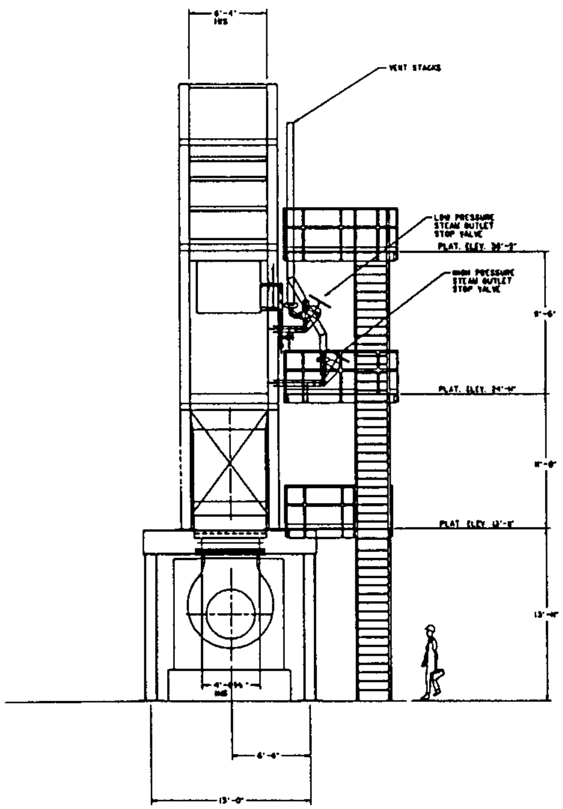
1. ———— PROCESS LINE (IST SCOPE).
2. * EQUIPMENT IS SUPPLIED BY IST, FIELD INSTALLED BY OTHERS.
3. -------- CUSTOMER SUPPLIED PIPING.
4. ■ EQUIPMENT IS SUPPLIED AND FIELD INSTALLED BY OTHERS.
5. ALL INSTRUMENT LINE ROOT VALVES ARE 3/4" (20mm) SOCKET WELD INLET BY 1/2" (12mm) FNPT OUTLET.
6. ALL DRAIN & VENT PIPING SHALL BE ROUTED TO A SAFE LOCATION BY OTHERS.
7. HRSG NO. 01 SHOWN, TAG NUMBERS ARE PREFIXED WITH # REFER TO VALVE AND INSTRUMENT LIST FOR FULL TAG DESIGNATIONS, SPECIFIC TO UNIT 01, 02 OR 03.

Innovative Steam Technologies

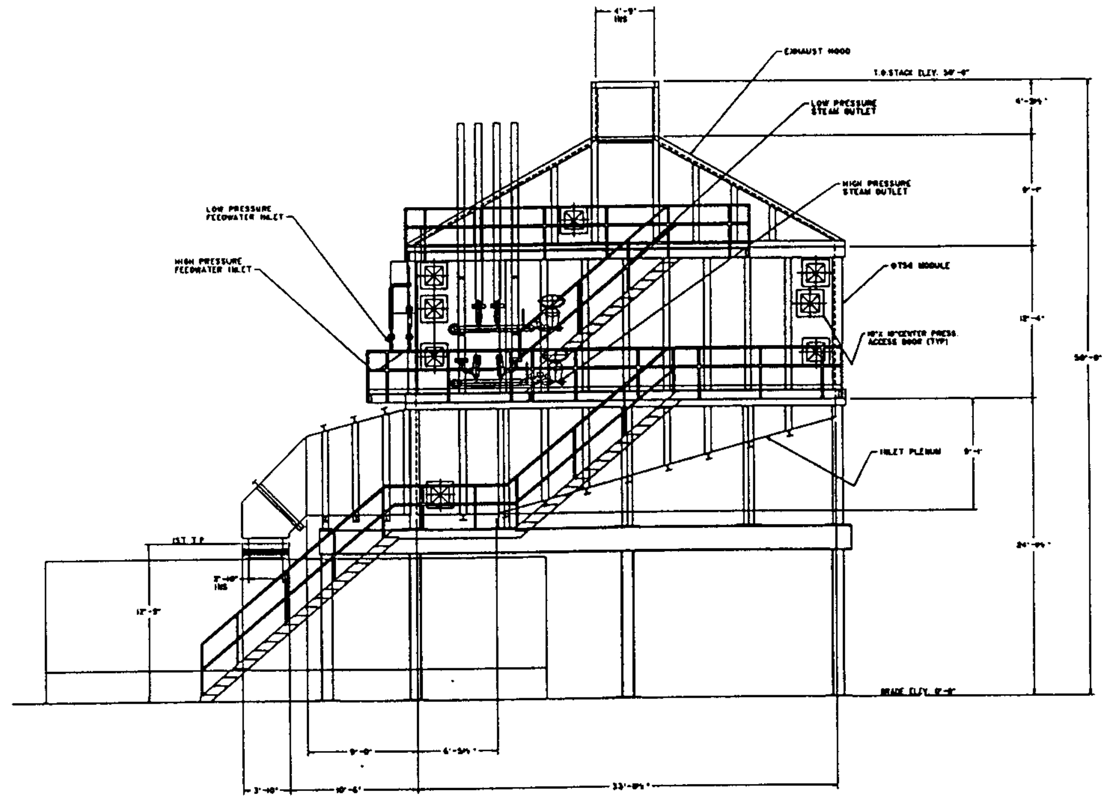
D.C.RELEASE		CUSTOMER: TYPICAL DUAL PRESSURE LM6000 OTSG			
DESIGN –	DATE: –	TITLE: FEEDWATER, STEAM AND EXHAUST GAS FLOWSHEET			
CHK. –	DATE: –				
DRN. C. MODOLO	DATE: 08/19/99	PROJ.NO. –	DWG. NO. –	A2	REV. 00
CADDS I.D. ACAD–			CODE NO. –	SHEET NO. 01 OF 01	

Appendix B.

Various OTSG Duct Arrangements

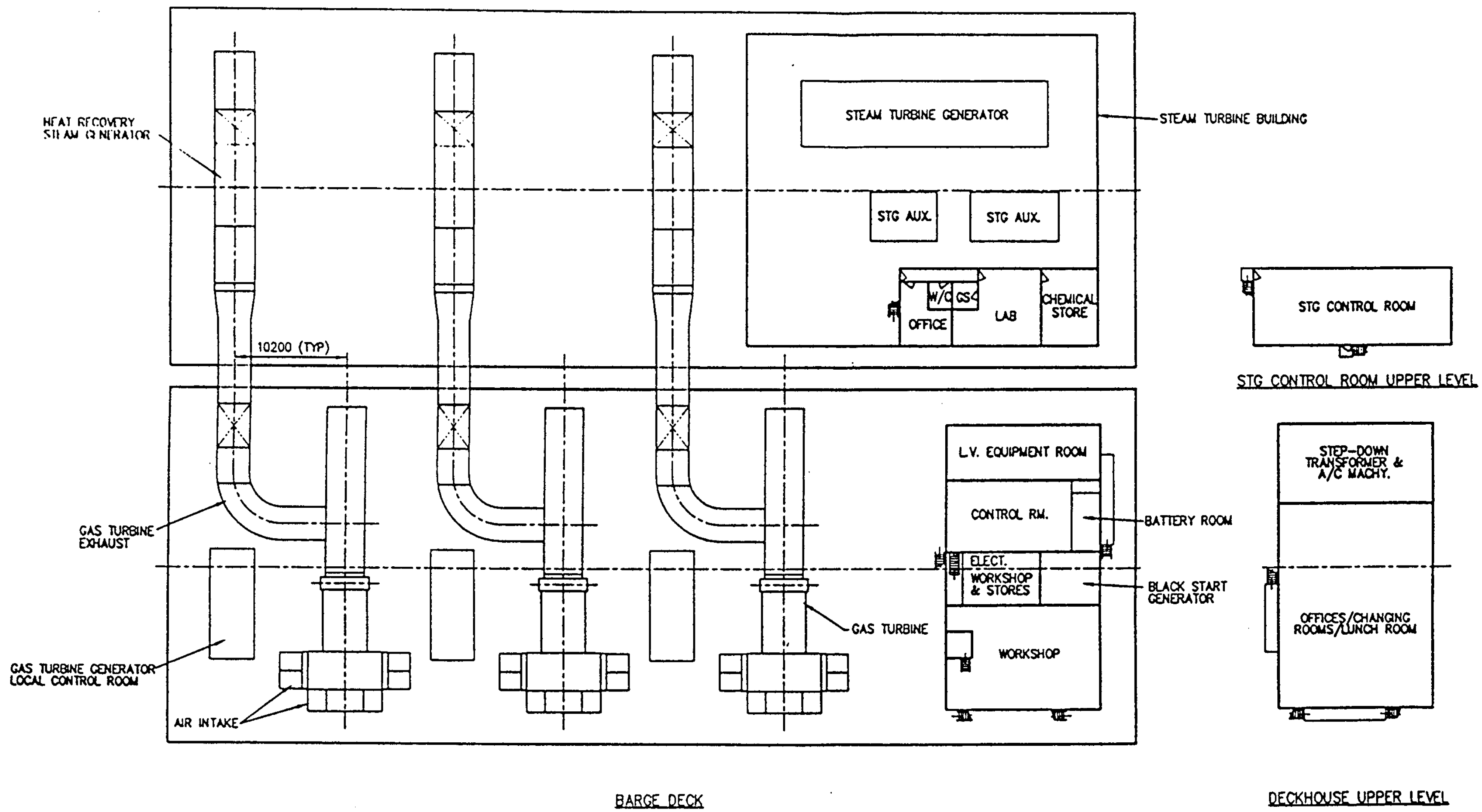


INLET ELEVATION



SIDE ELEVATION

FOR A COMBINED CYCLE FLOATING POWER PLANT



Appendix C.

Typical OTSG General Arrangement

DESIGN PRESS:	DESIGN TEMP:	ASME SECTION 1 HYDRO. TEST PRESS:	OPER. PRESS (MAX):	MANUFACTURER:
801 psig 5.52 MPa (gage)	900°F 482°C	1470 psig 10.13 MPa (gage)	750 psig 5.17 MPa (gage)	Innovative Steam Technologies
SERVICE: WATER & STEAM	HYDRO TEST TEMP: Amb. 70°F (21°C) to 120°F (49°C)	QCP INSP: PW-11	SAFETY VALVES: per PG-67, 68	YEAR: 1998
CODE CALC REF: CC: C99095 -S001 to S007		WELD LIST REF: WL: 195001		HEATING SURFACE : 2961 m2

THIS IS TO CERTIFY THAT THIS DESIGN FULFILLS ALL THE TECHNICAL REQUIREMENTS OF ASME CODE SECTION 1 ADDENDA : W1995

SIGNED: ____________

DATE: ____________

HIGH PRESSURE ZONE

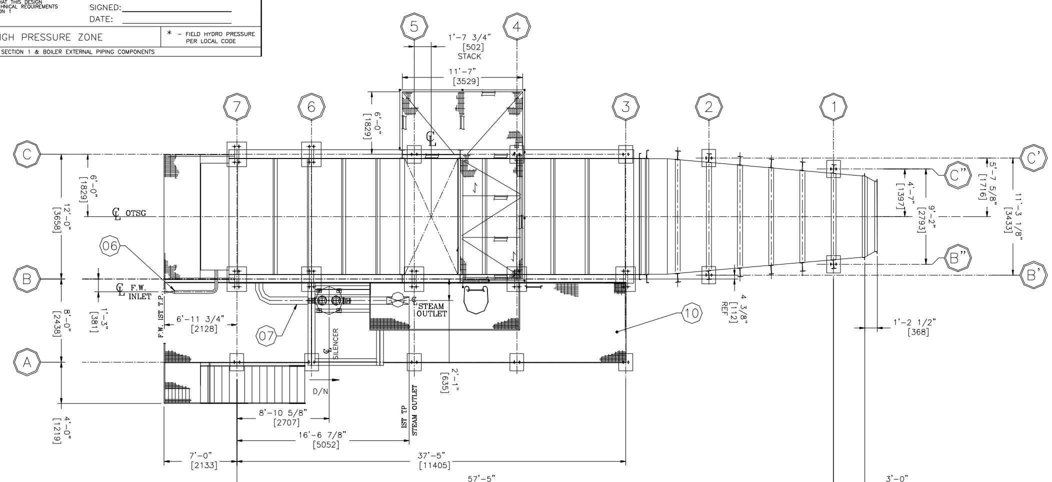
* - FIELD HYDRO PRESSURE PER LOCAL CODE

APPLICABLE TO ASME SECTION 1 & BOILER EXTERNAL PIPING COMPONENTS

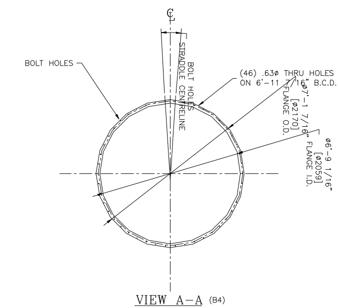
SHT	1	2	3	4	5	6
REV						

REVISIONS

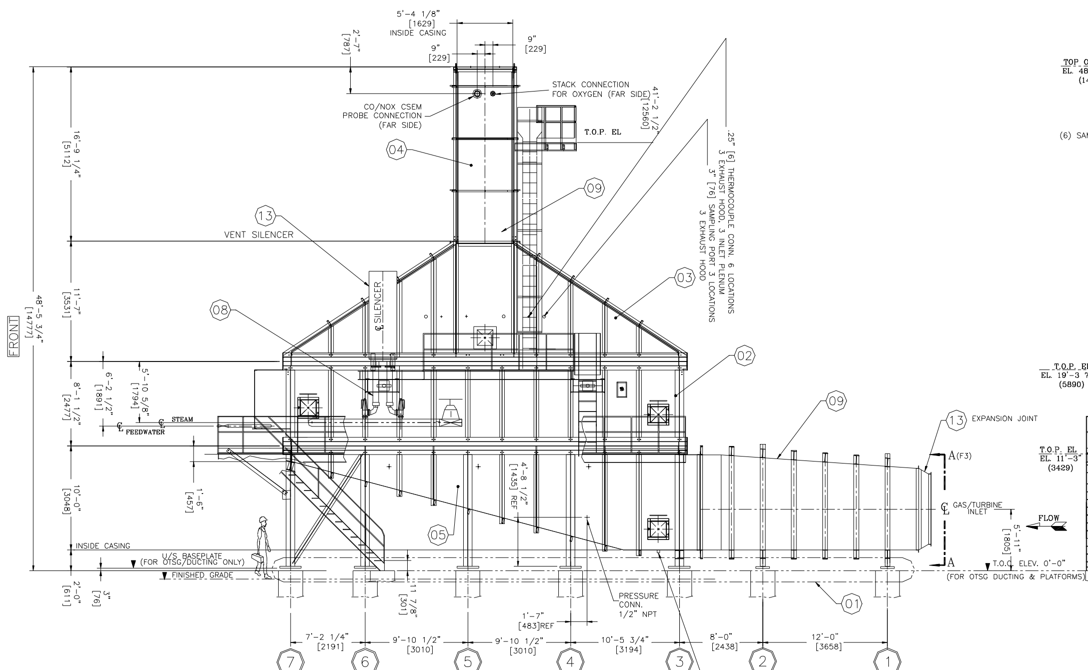
REV	ZONE	DESCRIPTION	BY	APP	DATE



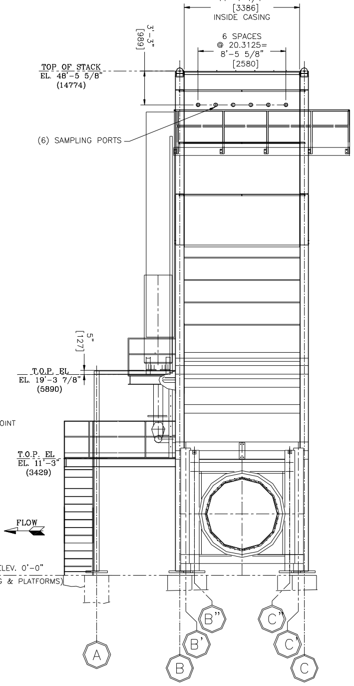
PLAN VIEW



VIEW A–A (B4)
EXPANSION JOINT INLET FLANGE HOLE PATTERN
SCALE 1 = 20



RIGHT SIDE ELEVATION
SCALE .25 = 1'-0"



INLET ELEVATION
REAR

PRELIMINARY

REFERENCE DRAWINGS:
FOUNDATION LOADINGS.....XXXXX2
BASEPLATE LAYOUT ASSEMBLY.....XXXXX3
FEEDWATER & STEAM FLOWSHEET.....XXXXX4

NOTES:
1. HEADERS LOCATED ON OPPOSITE END FROM GAS INLET.
2. STEAM OUTLET WILL BE ON THE RIGHT WHEN FACING HEADER END OF UNIT.
3. TYP. 12.00 [305] CLEARANCE FOR EXTERNAL STIFFENING MUST BE NOTED AND ADHERED TO BY OTHERS.
4. ALL PRIMARY DIMENSIONS & ELEVATIONS ARE IN FEET & INCHES. ALL SECONDARY DIMENSIONS ARE IN mm.
5. IST T.P. DESIGNATES IST TERMINAL POINT.
6. ALL EXTERNAL PIPING WELDS TO BE IN ACCORDANCE WITH ASME B31.1 1998 EDITION.

QUANTITIES SHOWN ARE FOR 1 UNIT ONLY

QTY.	U/M	ITEM	PART NO.	PART NAME	DESCRIPTION	MATERIAL	ZONE
1	EA	14	XXXX27-100	OTSG/DUCTING ERECTION	ERECTION DIAGRAM AND DETAILS		–
1	EA	13	XXXXX0-300	EQUIPMENT	EQUIPMENT LIST		–
1	EA	12	XXXXX0-200	VALVES	VALVE LIST		–
1	EA	11	XXXXX0-100	INSTRUMENTS	INSTRUMENT LIST		–
1	EA	10	XXXX32-100	PLATFORM ASSEMBLY	PLATFORM ASSEMBLY KIT		F5
1	EA	09	XXXXXX-100	TRANSITION DUCT	INLET TRANSITION ASSEMBLY		–
1	EA	08	XXXX26-200	PIPING ASSEMBLY	VENT STACK PIPING ASSEMBLY		C7
1	EA	07	XXXX25-100	PIPING ASSEMBLY	STEAM OUTLET PIPING ASSY.		F7
1	EA	06	XXXX24-100	PIPING ASSEMBLY	FEEDWATER INLET PIPE ASSY.		F7
1	EA	05	XXXX21-100	INLET PLENUM	INLET PLENUM ASSEMBLY		B6
1	EA	04	XXXX19-100	EXHAUST STACK	EXHAUST STACK ASSY		D6
1	EA	03	XXXX17-100	EXHAUST HOOD	EXHAUST HOOD ASSEMBLY		C5
1	EA	02	XXXX15-100	MODULE ASSY.	OTSG MODULE ASSEMBLY		C5
1	EA	01	XXXXX3-100	BASE PLATE ASSY.	BASE PLATE LAYOUT/ASSEMBLY		A4

-100 ← ASSY NO.

BILL OF MATERIAL AND PARTS LIST

TOLERANCES UNLESS OTHERWISE SPECIFIED
LINEAR DIMENSIONS ARE IN INCHES
TOL. ON 1 PLACE DECIMALS +/-
TOL. ON 2 PLACE DECIMALS +/-
TOL. ON 3 PLACE DECIMALS +/-
ANGULAR TOLERANCE +/-

THIRD ANGLE PROJECTION

D.C.RELEASE

Innovative Steam Technologies

MFG. –	DATE: –
PROJ.ENG. –	DATE: –
DES.SUPR. –	DATE: –
CHK. –	DATE: –
DRN. C. MODOLO	DATE: 08/17/99
N.H.A. –	EQUIP.MODEL LM6000
CADDS I.D. P:\.C99095.XXXX01-R00	

CUSTOMER: TYP. LM6000

TITLE: GENERAL ARRANGEMENT LM6000 OTSG & EQUIPMENT

PROJ.NO.	DWG. NO.		REV.
C99095	XXXXX1	A0	00
CODE NO. –	SCALE: 1 = 48	SHEET NO. 01 OF 01	

Appendix D.

Typical OTSG/HRSG Barge Mounted Combined Cycle Project Evaluation

Innovative Steam Technologies

Project: POWER-Gen Asia 1999	Date: August 19th, 1999	
IST Ref #: PXXXXX		
Capital Cost Evaluation		
	Supply Cost $USD*	
Description	**OTSG**	**Drum-type HRSG**
Supply cost for one (1) dual pressure heat recovery syteam generator designed to recover waste heat from one (1) LM6000 40MW GT.	$2,400,000	$2,206,00
Steam Paramaters		
HP Flow (t/hr)	41.13	41.13
HP Steam Temperature (deg.C)	419	419
HP Pressure (Bara)	59.71	59.71
LP Steam Flow (t/hr)	17.62	17.62
LP Steam Temperature (deg.C)	228	228
LP Pressure (Bara)	5.72	5.72

*Based on products designed, manufactured and produced in North America

Installed Capital Cost Evaluation (USD)

No.	Item	OTSG	Drum Type	OTSG Savings
1	**Erection**	150,000	600,000	450,000
2	**Diverter Valve & Bypass Stack**	0	500,000	500,000
3	**Commissioning, Boilout & Acid Cleaning**	10,000	100,000	90,000
4	**Barge Structural Foundations**	80,000	100,000	30,000
5	**Instrumentation & Control**	100,000	200,000	100,000
6	**Spare Parts**	20,000	50,000	30,000
7	**Blowdown System**	0	75,000	75,000
8	**Polisher***	(150,000)	0	(150,000)
*** Based on a four unit combined cycle plant**		*OTSG Advantage / Unit*		*$1,125,000*

Operating Cost Evaluation					
No.	Item (Operating Cost)	Comments	USD/Year	Assumptions	Present Value
1	Additional Feedwater Pump Power Consumption	10% More Power due to Orifice and Small Tubes	$52,560	100kw extra power consumption	($655,014)
2	Polisher Operating Cost More	Polish 100% of Condensate Flow (235t/hr)	$15,000	Treat 100% of condensate flow	($186,933)
3	Eliminates Blowdown Treatment Cost	2.5% x 235 t/hr = 5.6t/hr must be treated	N/A	No treatment at this plant	N/A
4	Make-Up Treatment Cost Less	2.5% x 235 t/hr (extra) = 5.6t/hr must be treated	($6,500)	2.5% less makeup	$81,004
5	Gas Side Pressure Drop is Less	(250mm:HRSG) vs. (150mm:OTSG)	($220,752)	0.26% X 40MW X 4 (for 38 mm H2O less back pressure)	$2,751,058
6	Lower Maintenance Cost	1/2 the number of valves & instruments & No Diverter Damper	($15,000)	Assumed value	$186,933
7	Less Operating Staff	One Less Operators Per Shift	($40,000)	Assumed value	$498,488
8	Eliminates Drum Chemical Injection	Must Treat for 235 t/hr	($10,000)	Chemical injection into drum	$124,622
9	No Efficiency Loss due to Blowdown	No Heat Loss in Blowdown Stream	($214,445)	2.5% continuous blowdown = 0.68 % X 60MW (ST)	$2,672,456
10	No efficiency loss due to leakage through diverter & bypass stack.	Leakage through diverter	($315,360)	1% leakage = 1% steam flow X 60MW (ST)	$3,930,083
				Total Present Value of Operating Cost Factors	$9,402,698

A positive total present value indicates OTSG system is advantages.

A negative total present value indicates HRSG system is advantageous.

Present Value Assumptions

Interest Rate	0.05
Number of Years	20
Cost of Power (USD/kwh)	0.06
Plant Capacity	100%
Number of GTs	4
GT Power Rating	40MW
Number of HRSGs/OTSGs	4
Number of Steam Turbine	1
Steam Turbine Power Rating	60MW
Plant Capacity	200MW
Total Plant Condensate Flow	235 t/hr (metric)