Optimization of Gas Turbine HRSG Cycles
Some Concepts

AKBER PASHA
Manager of Design Engineering
Henry Vogt Machine Co.
Louisville, Kentucky

ABSTRACT:

Today the Heat Recovery Steam Generator (HRSG) has become an integral part of the combined cycle or Cogen plant because of its influence on other equipment. Therefore, the optimization of the HRSG has become one of the prime targets to improve the overall efficiency.

The paper presents recent developments and concepts used in HRSG design which improve either the efficiency or range of performance or both. The paper discusses three major areas of a HRSG - Superheater/Reheater, Economizer, and LP Evaporator/Feedwater Preheater. Depending upon the requirement, the user can implement one or more of the concepts to improve the total performance and/or the reliability.

INTRODUCTION:

The heat recovery steam generator (HRSG) has become an integral part of the combined cycle or the cogeneration plant. It has become imperative to optimize the HRSG design to improve the total system efficiency. The optimization is also needed to broaden the range of operations so that the plant operating flexibility may not be compromised. Therefore, the optimizing criteria needs to be discussed along with the effect of each criterion on the plant performance.

The following paragraphs describe various HRSG cycles which either increase the total heat recovery or improve the operational flexibility and the range of operating conditions. Specific conditions need to be defined and evaluated before a particular cycle or
cycles can be adopted. However, there is no distinct line between any of these. Sometimes, the same cycle may increase the heat recovery as well as the operating range, and other times heat recovery may increase at the expense of the operating flexibility. Each cycle is discussed with its impact on the heat recovery or the operational flexibility.

A typical combined cycle HRSG (Figure 1) consists of a high pressure system with superheaters, evaporator and economizers; an intermediate pressure system with superheater, evaporator and economizer; a low pressure system with superheater and evaporator; an intermediate pressure reheater; feedwater preheater, deaerator and steam attemperators. Selective Catalytic Reactor (SCR) and carbon monoxide converters as well as a supplementary firing burner can also be provided, if specified.

The steam is supplied to the steam turbine at various pressures, to gas turbine for injection and to the deaerator.

A typical HRSG for cogeneration will also have similar sections with the exception of a reheater section. Generally, the steam is used for process and injection because the steam turbine may not be present.

To help in reducing the attemperator spray, a supplemental burner can be placed in between the superheater stages (Figure 3) when approximately the same steam temperature is needed both in the fired and the unfired modes.

Other configurations, such as counter current flow, superheaters downstream of evaporator section etc., have been used in extreme cases.

**REHEATER**

Reheating the exhaust steam from the High Pressure (HP) stage of the steam turbine and reintroducing into the Intermediate Pressure (IP) stage is common in conventional type boilers for power plant. But, it is a new feature for HRSGs. The basic difficulty is due to very close, if not identical, steam temperatures. With the close approach temperature between gas turbine...
exhaust temperature and the steam temperature, it is not possible to put the superheater and reheater sections one after the other as is done in conventional boilers (Figure 4).

numerous iterations, it was found that two reheater sections and two superheater sections are sufficient most of the time for an optimum configuration.

The reheater, since it operates at a lower pressure, is the first in the gas path (Figure 6) because of metallurgical reasons. Attemperators can be provided, as needed, to control the steam temperature both for the reheater and the superheater.

Reheater design is more complex than the superheater design because of high superheat temperature, low steam pressure, and low pressure drop requirements. At present, most of the cycles are optimized at a pressure of 300 to 500 psi at the HP steam turbine exhaust with about 35 to 50 psi total pressure drop on the steam side. Pressures lower than these present problems due to high specific volume and low pressure drop availability. Steam side pressure drop also influences steam line sizes. For the same amount of steam, the reheater line may be a 24" nominal diameter, whereas a superheater line may be only 10" in diameter.

An alternative is to put both the superheater and the reheater in parallel or side-by-side in the gas path so that both are exposed to the same gas temperature (Figure 5). But, this alternative gives very unpredictable results because of variations both in flow and temperature of the exhaust gases. The uncertain variations in gas flow result in wide swings in the steam temperatures. Since the duties in these sections, superheater and reheater are not the same, the exit temperature from the sections would not be the same resulting in unpredictable performance in downstream sections. There is also a possibility of uneven flow and cross-flow of the gases from one side to the other because of the difference in gas temperature and pressure on each side. The gas pressure is different because the required surfaces, duties and temperatures, all are different; hence the gas side pressure drop would be different. Experience with parallel or side-by-side economizers have shown the same trend.

The optimum solution to date, is to put these sections in series, superheater and reheater sections from two to four each following each other, each heating the steam to an appropriate temperature. After

The supplementary burner is used when the steam supply is to be varied over a range without affecting the GT electrical power output. Generally, the steam capacity can be doubled to that of unfired capacity without major changes in the metallurgy or the design. This higher capacity may result in a firing temperature of 1600 to 1700 degrees Fahrenheit.

Often times, when the power plant is being started, it is possible that there would not be any steam supply to the reheater. In those cases, either part of the HP steam is bypassed into the reheater to keep the tubes cool or the reheater can be run dry. The HRSG manufacturer can be consulted to establish a maximum Gas Turbine (GT) exhaust temperature when the reheater can run dry.

**SUPPLEMENTARY BURNER**

The supplementary burner is used when the steam supply is to be varied over a range without affecting the GT electrical power output. Generally, the steam capacity can be doubled to that of unfired capacity without major changes in the metallurgy or the design. This higher capacity may result in a firing temperature of 1600 to 1700 degrees Fahrenheit.

Generally the burner is located upstream of all heat transfer sections (Figure 2.B). However, as indicated in Figure 3, it can be located in between the superheater sections. This reduces the amount of desuperheating and increases the capacity of heat input.
because the gas temperature would be lower than the exhaust temperature from the gas turbine having passed through the superheater.

Locating the burner between superheater sections increases the length and cost of the HRSG to some extent because of empty duct, which will be a full section duct required to accommodate the flame downstream of the burner.

**INJECTION OR AUGMENTING STEAM**

Steam is injected in the gas turbine to reduce the NOx concentration. Extra steam can be introduced into the gas turbine to augment the power output. In a three-pressure level HRSG, the intermediate pressure steam is generally used for the introduction into the gas turbine. When there is a reheater, the cold reheat steam can also be used for the injection. If the steam pressure and temperature are higher, the injection steam can be taken from the outlet of the HP superheater No. 2. (Figure 7). An attemperator and Pressure Reducing Valve (PRV) are necessary to reduce the steam conditions to the injection level. Most of the time, the injection steam is not constant and if the injection steam system is designed for natural gas requirement rather than the fuel oil requirement, extra injection steam is needed. At that time steam will be taken either from the HP superheater or it can be supplemented by some other steam supply to put the required amount of steam in the gas turbine.

Sometimes, the gas turbine can be run without introducing any injection steam or with the dry combustor. In those cases, the produced IP steam needs to be sent to the condenser or disposed of in some other manner. If designed properly, the IP system can be bottled-up to produce no steam.

**SELECTIVE CATALYTIC REACTOR**

Most prominent among the monitored emissions for a GT plant are oxides of Nitrogen (NOx) and Carbon Monoxide (CO). Steam is injected in the GT to reduce NOx levels. However, these reduced levels may still be higher than the acceptable limits. Steam injection, in addition, increases the CO emission. NOx is broken into Nitrogen and water with the help of a catalyst in a selective catalytic reactor (SCR). A small amount of ammonia is injected to facilitate the reaction. Both the ammonia injection grid (AIG) and the SCR need to be located very carefully for the optimum reaction. A temperature window of 650-750°F is generally suggested. As shown in Figure 1, the SCR is embedded into the HP evaporator section (Fig. 8) where the specified window can be found and also the fluctuations in the temperatures are very minimum under all operating conditions. The AIG needs to be located some distance ahead of the SCR so that ammonia can mix with the gases. For a CO converter, a temperature of about 900°F is most commonly used and is generally located downstream of the superheater.

The SCR is very effective with natural gas firing, whether in the GT or the supplementary burner. But, if sulfur burning fuels are used, there is a possibility of the formation of ammonium bisulfate which will foul the external surfaces of the economizer tubes. Some sort of periodic water washing arrangement and draining of the water needs to be provided in the HRSG. A regular soot blower arrangement may not be very effective.

At present, the SCR effectiveness guarantee is from one year to three years. After that time, the catalyst may need to be replaced. The removal and disposal of the spent catalyst and the replacement of the new catalyst should be taken into consideration.

**ECONOMIZER**

The location of the economizers, particularly for the high pressure system, is very critical not only for the most cost effective design, but also for extracting the most high pressure heat. One way to achieve this is to distribute the HP economizer surface at various locations (Figure 1). This will enable the heat to be extracted at a higher temperature difference thus requiring less heat transfer surface. The temperature difference between the saturation and water at the economizer outlet, or the economizer approach temperature, needs to be as low as possible to produce the maximum amount of high pressure steam. However, these days when the HRSG needs to be operated at various off-loads and ambients, low approach temperature HRSGs have a tendency to produce steam in the economizer at some off-load condition. A 15°F approach temperature is commonly used, but if the operating conditions vary over a wide range, there is always a possibility of steaming in the economizer. This can be avoided by
providing the control valve at the outlet of the HP economizer (Figure 9). This will preclude the steaming in the economizer by maintaining a higher pressure in the economizer. The economizer can be designed and operated at a pressure of 2400 psig, whereas, the evaporator and superheater section may operate at 1500 to 1600 psig. However, if the range is wider, some water may be bypassed and mixed at the outlet for low loads. At a load of 10% or less, the above arrangement may still not be satisfactory. In such cases, extra water is pumped through the economizer and dumped to the condenser (Figure 9). Sometimes, complete bypass of the economizer may be necessary. However, this is not recommended for sustained operation.

Deaeration of feedwater is essential to avoid corrosion due to oxygen in the water. The most common way to remove the dissolved oxygen from the feedwater is to heat the water in a deaerator where water is sprayed and mixed with the incoming steam. This strips the oxygen from the water. Deaerators (DA) can be of two types. One is an integral deaerator wherein the deaerator is provided on top of the low pressure boiler drum (Figure 1). Steam is produced in the low pressure section of the HRSG and rises through the common nozzle to the deaerator. The water is sprayed from the top which mixes with the incoming steam. The oxygen is removed and the water drops back into the low pressure drum. The low pressure drum also serves as a storage tank to feed the high pressure and intermediate pressure pumps. A remote deaerator and a tank can also be provided wherein the steam from the low pressure drum can be sent to the deaerator. The deaerator tank will supply the water to the HP and IP systems. Integral deaerators are becoming more popular because of the flexibility of the operation and the avoidance of a separate tank to store the water. At off-load conditions, it is possible that the low pressure drum may produce more steam than necessary or less steam than required for deaeration. If there is less steam available, some steam can be pegged from the IP system (Fig. 10), or in rare cases, from the HP system to supplement the steam requirement for the deaeration. If the steam production is more than what is required, the steam operating pressure can be raised to match the steam requirement. This floating type of arrangement often helps in maintaining a self-controlling system.

Hot water deaeration is also used sometimes where water is heated in an economizer type heater as a part of the HRSG, sent to the remote deaerator wherein the water will be deaerated, and then sent to the HP and IP systems. This type of deaeration is not very popular.

WATER PREHEATERS

Various schemes have been provided to reduce the stack temperature to as low as possible. Most prevalent among them is a feedwater preheater. Water, whether it is condensate or make-up water, is preheated in the feedwater preheater by utilizing the gases. It is then pumped to the deaerator at a suitable approach temperature. This reduces the duty on the deaerator as well as extracts more heat at lower surface requirement from the HRSG gases. Because of this facility, some of the low pressure steam can be sent for other uses such as introduction into the LP steam turbine or for the process. However, because of the acidic dew point considerations, as well as deaerated water inside the feedwater preheater, the material needs to be selected very carefully.

Preheater Material Selection

Inside Corrosion

The condensate absorbs oxygen because of air leakage into the condenser. The makeup water contains oxygen and also picks up oxygen in tanks, pump lines, etc. The oxygen content of the water entering the HRSG system depends upon the amount of leakage and percentage of makeup since the makeup water generally contains more oxygen.

If the oxygen content is 50 parts per billion (ppb) or less, then the oxygen attack is very minimal and carbon steel can be used for all surfaces in contact with water (inside tubes). If the oxygen content is higher, then stainless steel is needed to protect against oxygen pitting.
Outside Corrosion

If the gas turbine uses natural gas only, the amount of sulfur dioxide in the exhaust gas is very small because only traces of sulfur are present in the fuel. The formation of, and corrosion due to, sulfuric acid is very remote unless the tube metal temperature is below the water dew point. So to avoid any corrosion, all metal surfaces (tubes) with a metal temperature at or below the water dew point should be of stainless steel and the fins should be an alloy material.

If oil or other fuel with higher sulfur content is used, then the preheater is bypassed, thus increasing the stack temperature. Absence of water in the tubes makes the metal temperature the same as the gas temperature which will generally be above acid dew point. Thus oil firing does not have any influence on the material selection.

Bypassing of preheater decreases the heat recovery, but also decreases the cost of the equipment as a full stainless steel preheater need not be used. If low stack temperature is needed in the oil firing mode with higher sulfur content, all material below the acid dewpoint should be stainless steel.

Series 300 vs 400 Stainless Steel

The austenitic or Series 300 stainless steel is little more corrosion resistant than 400 Series and is easier to work with. However, if the atmosphere (exhaust gases) contain chlorine, austenitic steel may not be used, as it is susceptible to chloride corrosion. In such cases, ferritic steels (400 Series) may have to be used.

Providing a feedwater heater gives more flexibility to the HRSG system. For example, if the fuel oil is being used in the gas turbine, then to preclude the possibility of acid condensation, the full feedwater preheater may be bypassed and the water can be directly sent to the deaerator (Figure 10). When there is no requirement for low pressure steam, the feedwater preheater can be bypassed and the steam can be used for deaeration by introducing all the condensate and make-up into the DA itself. To avoid corrosion due to dissolved oxygen, the makeup can be fed directly into the deaerator while the condensate goes through the preheater. When the water temperature is very low and there is a possibility of water condensing due to low dew points and high moisture content in the gases, it is necessary to heat the incoming water to the feedwater preheater. In those cases, the water may be recirculated to the inlet thereby increasing the inlet temperature of the water.

CONCLUSIONS

Various cycles to improve the HRSG efficiency and flexibility are described in the above paragraphs. A total cycle analysis combining all the equipment such as gas turbine, steam turbine, HRSG, condenser, etc., is necessary to establish the applicability of any one or all of these arrangements.

Writing specifications for an HRSG and buying according to the specification without getting the input from the prospective manufacturers has become a thing of the past. Today, the customer needs to work with an engineer and along with them select the suppliers for all the equipment. This selection should be based on initial quotes, experience, stability and reputation of the suppliers. After the team has been established, the total system needs to be redesigned to achieve the project's objectives. Getting the competitive bids for each piece and selecting them on the basis of individual performance seems to cause more confusion and ambiguity and may increase the cost due to omission of interface equipment. Working together on a team basis seems to be the only way to achieve a viable and cost effective system with an optimum life.

REFERENCES USED IN PREPARING THIS PAPER


ACKNOWLEDGEMENTS:

The author wishes to thank Mr. David Pierce for preparing the sketches and Ms. Diane Olson for diligently typing the mats.