

Deaerating condenser boosts combined-cycle plant efficiency

Studies show savings in equipment and plant space and the ability to deaerate large quantities of makeup water using only turbine exhaust steam in a new system

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A new system of steam condenser dissolved oxygen control has found favor in the combined-cycle cogeneration market. Savings in equipment, a reduction in building size (and plant height), and the ability to deaerate large quantities of makeup water using only turbine exhaust steam are the reasons.

In earlier days, no condenser manufacturer guaranteed condensate oxygen levels of 7 parts per billion (ppb) under any operating condition. Instead, guarantees were limited to Heat Exchange Institute (HEI) standards.

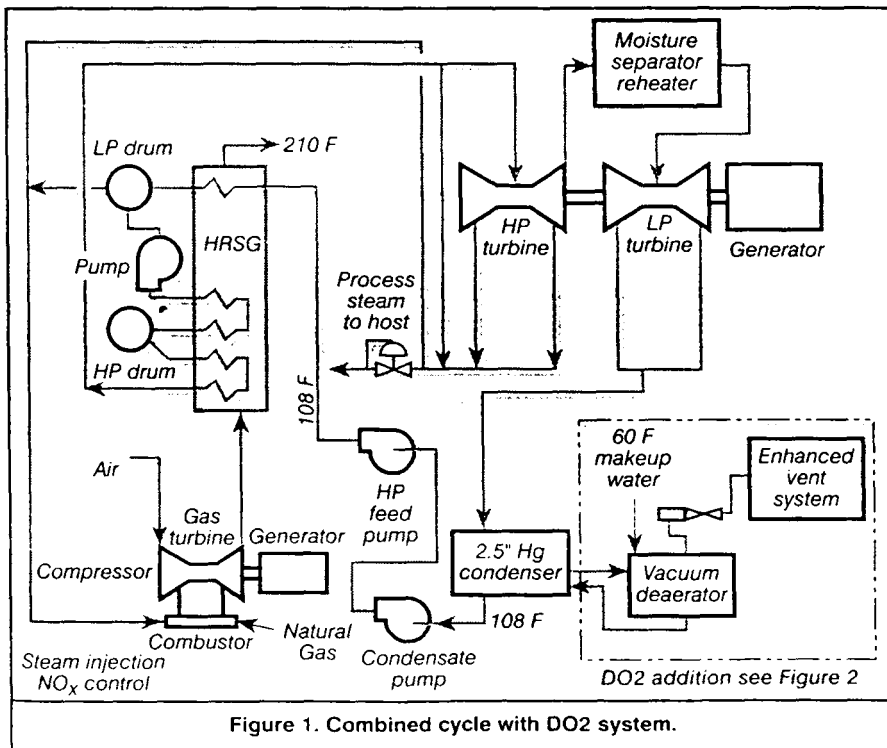
HEI standards promise 0.005 cc/I (7 ppb) dissolved oxygen (DO) in the condensate only if (1) the air leakage is reduced to a fraction of the tabulated leakage rates; (2) the condenser makeup is limited to 3%; or (3) the condenser is operated at or near full load and with design cooling water conditions.

Condition (3) is not stated as a DO limitation by HEI. It is a limitation on the condenser vacuum and the condensing temperature approach, both of which affect condensate dissolved oxygen levels. HEI standards for steam surface condensers indicate that these limits can only be achieved as follows: at or near full load:

at or near the design cooling water temperature, and then only if air leakage is reduced to 25% of tabulated values for flows up to 20 scfm, and to 15% of tabulated values for flows up to 40 scfm. Maximum air leakage in any case may not exceed 6 scfm.

Reports by the Electric Power Research Institute (EPRI) consistently describe DO increases during start-up and at reduced load. Specifically, EPRI NP-2294 attributes high dissolved oxygen in steam condenser condensate to inadequate venting at reduced load. This report indicates that the steam condenser air cooling section became ineffective under partial load conditions. The resultant increased vapor tends to overload the vent system at the same time as the vent system capacity is reduced at lower condenser pressures. Air inleakage is simultaneously increased.

The combination of increased vapor loading and decreased vent system capacity causes rapid air buildup in the condenser. This raises the oxygen partial pressure and increases the absorption of oxygen in the steam condensate in accordance with Henry's Law. Reports continue to be issued advocating methods to prevent oxygen absorption (i.e., nitrogen blanketing of condensate storage tanks), a sure indication that the problem remains.



Makeup water requirements for combined cycle and combined-cycle cogeneration plants exceed those of conventional fossil plants for a number of reasons. Combined-cycle plants often employ steam injection in the gas turbine for NO_x control. This steam is vented along with the turbine exhaust gas and is lost to the system. Combined-cycle cogeneration plants also export steam to the host user at varying flowrates.

A recent oxygen removal equipment development addresses the problems associated with high levels of makeup water in cogeneration plants. The first application of this new condensate oxygen control system (called DO₂) was at Gilroy Energy, a cogeneration facility designed, constructed and operated by Bechtel. The anticipated wide variations in load and makeup water requirements indicated that high condensate dissolved oxygen levels could be expected.

Bechtel engineers participated in early EPRI studies of this problem and were aware that special measures for DO control would be necessary. They chose the new system and that was fortunate because the local utility required the power plant to shut down for six hours daily soon after the early design stages.

Studies show that power plants encounter severe DO excursions during start-up. However, dissolved oxygen in a DO2 condenser system has not exceeded 7 ppb and usually remained below 5 ppb even though the load varied widely, cooling water temperatures fluctuated, and make-up flows with DO levels of 8000 ppb were added to the system.

Conventional power plants heat feedwater most efficiently by sending turbine extraction steam to the feedwater heaters. Elimination of the pressure deaerator, which is advantageous in a combined-cycle plant, is not good thermodynamics for a conventional power plant. Condensate oxygen control is, however, important to both plants and the new system is applicable to either power cycle, even when makeup water needs are low.

BECHTEL PROJECT BACKGROUND

Bechtel completed the Gilroy facility in early 1988. The new condensate oxygen control system provided cold deaerated water containing less than 7 ppb of oxygen to the heat recovery steam generator (HRSG) using only waste turbine exhaust steam for the deaeration of large quantities of highly oxygenated makeup water.

Condensate dissolved oxygen levels seldom exceed 5 ppb here despite operating conditions far in excess of the limitations specified in the HEI standards. These conditions also exceeded those reported by EPRI, wherein high dissolved oxygen developed in boiler feedwater in conventional power plants.

The simplified combined cycle that resulted from the new system (Figure 1) reduced plant costs, increased power, and improved efficiency. It eliminated equipment, which led to reduced maintenance and improved plant reliability. Space and structural savings also were achieved.

Combined-cycle power plants that use clean fuels can achieve maximum efficiency when HRSG discharge temperatures are lowered to near 200 F, rather than the 300 F range which must be maintained when using fuels having acid dew points below 300 F. This difference could result in about a 10% increase in gas turbine exhaust heat recovery.

Colder feedwater temperatures than those available from pressure deaerators attain a lower HRSG discharge temperature. It is essential that this feedwater be thoroughly deaerated to 7 ppb of oxygen to prevent corrosion. Because HRSG exhaust temperatures in the 200 F range are above

the acid dew point when firing with clean fuels, carbon steel tubes can be used in the cold end of the HRSG. Hence, the device's size and cost may be reduced.

The source of cold "deaerated" water is condensate from the steam surface condenser, which usually is available at 101 F-115 F (2-3 in. Hg Abs). This cycle design is simple, less costly, and more efficient than a cycle using a pressure deaerator.

The new system has no pressure deaerator, elevated storage tank, multiple extractions from the steam turbine, or extraction feedwater heaters, and no associated piping. Its piggyback pump arrangement assures boiler feed pump NPSH and eliminates surge problems associated with conventional deaerating heaters. The cold water cycle is indeed ideal, offering lower investment, higher efficiency, increased power, and easier maintenance.

DO CONTROL METHODS

All power plants require boiler feedwater DO levels to be below 7 ppb, and 5 ppb is recommended for nuclear plants. Surface condensers can produce these desired oxygen levels only under the most stringent operating conditions, and certainly not when adding makeup water to the condenser.

Although oxygen could enter the system between the condenser hotwell and the condensate pump, no inleakage should occur on the discharge side of the pump. The need to remove oxygen in the pressure deaerator can be attributed only to poor steam condenser deaeration, and to makeup water added to the system.

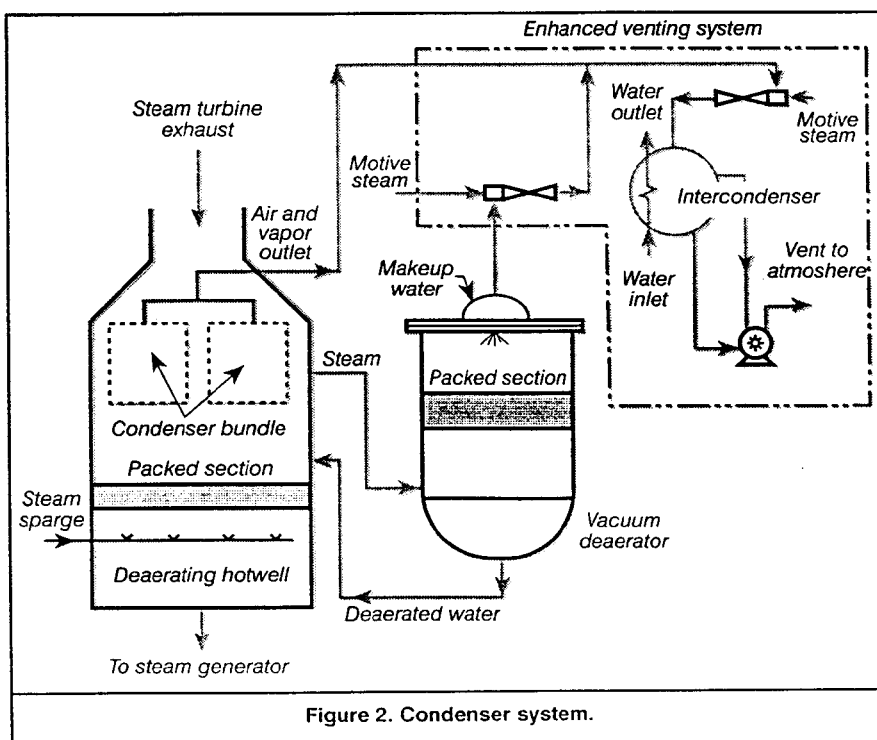


Figure 2. Condenser system.

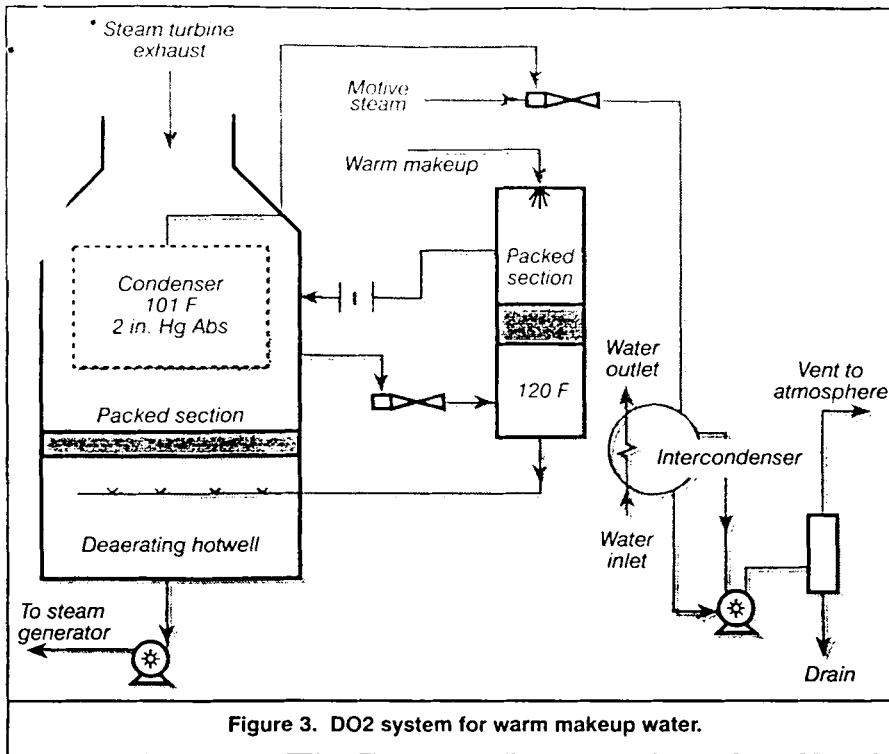


Figure 3. DO2 system for warm makeup water.

Conventional power plants seldom require makeup water exceeding 3% to 5% of condenser flow and HEI permits dumping this into the steam condenser. There would be no need for the pressure deaerator if the condensate reaching it was already deaerated. It would be much simpler and less expensive to heat the feedwater in another closed feedwater heater. We must conclude that deaerating condensers cannot always be relied upon to provide properly deaerated feedwater to the steam generator, particularly in a combined cycle cogeneration system.

It is imperative to minimize the air entering the feedwater system. Leaks in the condensate pump and into the hotwell can be eliminated by welding joints, water sealing and other means. Air entering the steam condenser from gland seals and other sources must be exhausted by the venting device. To prevent oxygen in the steam condenser from dissolving into the condensate, the oxygen partial pressure within the condenser must be so low, in accordance with Henry's Law, that no more than 7 ppb of oxygen can go into solution. This can be accomplished by sizing the venting equipment to remove about 25 pounds of water vapor per pound of air. This is approximately ten times the amount specified by HEI standards. Under these conditions dissolved oxygen will not exceed 7 ppb.

To maintain this low partial pressure throughout the steam condenser requires redesign of the condenser internals. Present condensers contain an air cooling section designed to limit water vapor carryover to 2.2 pounds of water vapor per pound of dry air. Condenser internals must be redesigned to minimize gas/vapor pressure

loss despite the ten-fold increase in vapor flow. Oxygen partial pressure at all points within the condenser must be held to low values.

Steam surface condenser designs aimed at dissolved oxygen control must also be directed toward preventing condensate subcooling. Reheating the condensate with steam drives out oxygen that has been re-absorbed. These objectives are achieved by bundle design, the use of steam lanes, and liquid deflection plates—and sometimes supplemented by sparge steam in or above the hotwell.

To properly deaerate liquid, it should be finely dispersed in thin films or droplets. Within a surface condenser, there is neither a fine dispersion of liquid nor is there sufficient contact time. Thick liquid films cover the tubes (particularly the lower tubes) and deflection plates only lower descending liquid into thick sections that are difficult to deaerate.

Deaeration in a surface condenser is difficult under the best conditions, but at part load, the patterns vary widely. An additional disturbance of flow patterns occurs as condensate returns are dumped into the condenser, requiring shields, dispersion pipes and headers. No deaerator manufacturer would consider placing a cold heat exchanger bundle in the middle of the deaerator. Present steam condensers should be classified as good aerators, not deaerators.

SPECIFICS OF THE NEW SYSTEM

Although the DO2 (Figure 2) has a water vapor/air capacity more than ten times that specified by HEI, energy requirements are not increased proportionally. This is accomplished either by adding an extra stage to the conventional two-stage ejector, or by using a hybrid system (steam ejector/intercondenser/two-stage liquid ring vacuum pump). The increased vapor flow removed from the con-

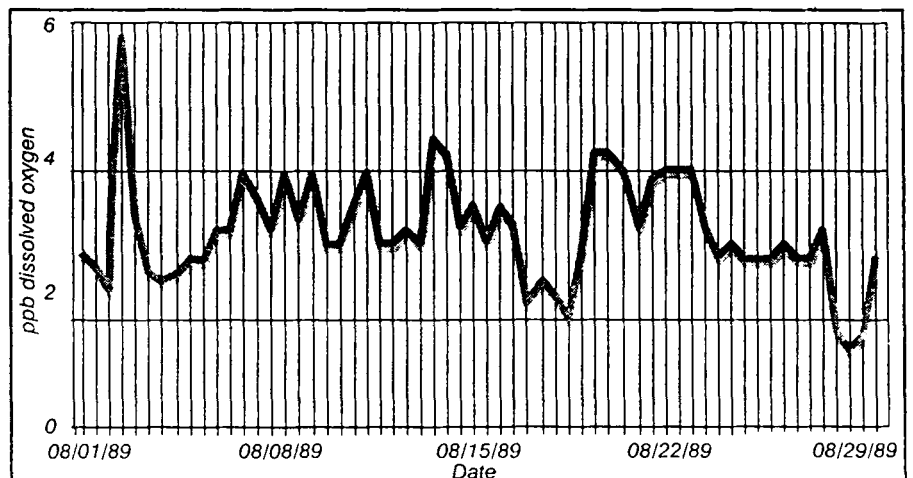


Figure 4. Log of condensate dissolved oxygen.

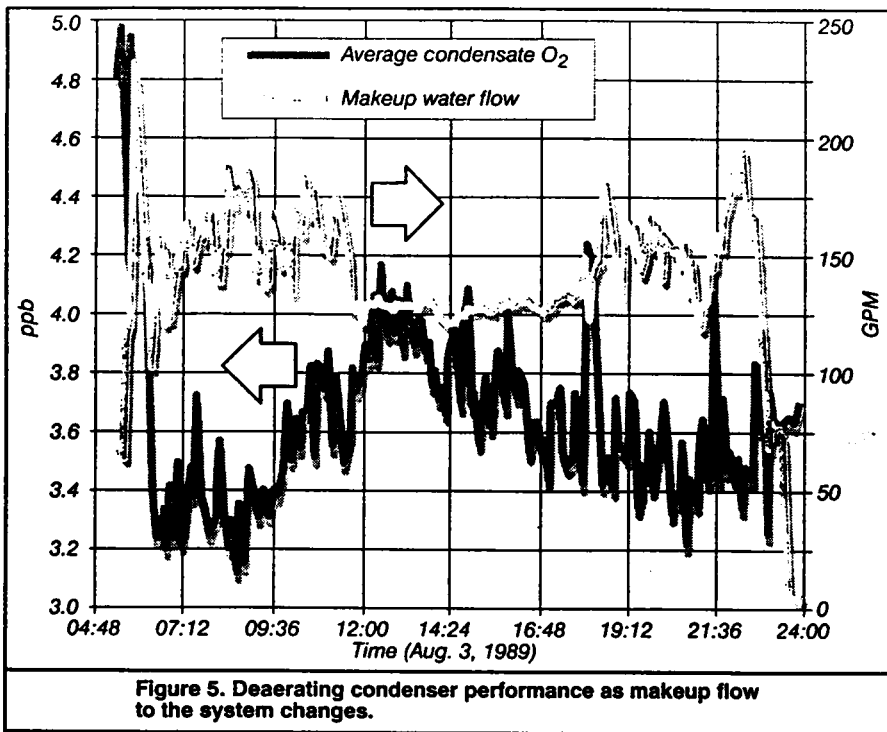


Figure 5. Deaerating condenser performance as makeup flow to the system changes.

denser is compressed over a short range (which minimizes motive steam flow) and condensed in the intercondenser. The vapor leaving the intercondenser is compressed atmospheric pressure by the two-stage ejector or two-stage liquid ring vacuum pump.

For combined-cycle power plants requiring large quantities of cold deaerated makeup water, the system is not a complete solution to the problem. Makeup contains high levels of dissolved oxygen, often exceeding 8000 ppb. If this oxygenated water is dumped into the steam condenser in small amounts, the effect is small and some deaeration occurs as the liquid descends through the tube bundle. However, HEI limits this makeup flow to 3% if 7 ppb of dissolved oxygen is required. Makeup flows to cogeneration plants usually exceed this level by a wide margin. Makeup requirements can easily exceed 50% and have sometimes reached 85% with simultaneous low steam load.

Large volumes of makeup water introduced into a condenser will raise DO levels well above desired levels and cause damage to downstream equipment. It is important to note that high makeup water requirements imply a variation in condenser load. That is, as makeup levels increase, the steam load to the condenser decreases. Therefore, the condenser is operating at part load and DO is increased.

To solve the makeup deaeration problem, the DO2 system routes all makeup water over a vacuum deaerator. This is a packed column supplied with deaerating steam directly from the steam condenser body. This steam, which would otherwise be condensed on the condenser surface, is used to heat and deaerate the makeup water. The

makeup water drains into the steam surface condenser where it joins condensate from the tube bundles. The deaerated makeup water mixes with the condensate and descends to the hotwell.

The hotwell is designed to further deaerate the mixture, which can only enter the lower segregated portion of the hotwell through a section of packing. A small amount of steam sparged into the lower portions of the hotwell must flow up through the packed section, thus reheating and deaerating the descending liquid.

To accomplish deaeration in the vacuum deaerator, the liquid must be heated over a required temperature range. When condenser loads are low and cooling water temperatures are also low, or when makeup water temperatures are elevated due to mixing with hot drains, the available condenser steam temperature may be too low to heat the water through the required deaerating range. The system shown in Figure 3 was developed to cope with this situation. This system uses turbine exhaust steam compressed to a higher pressure and temperature, thus supplying the vacuum deaerator with sufficient heat at an elevated temperature. Use of the thermocompressor reduces the amount of high pressure motive steam required to one-third of the total flow to the vacuum deaerator.

EPRI report AP-5815 notes the benefits of the cycle depicted in Figure 1. "In combined-cycle plants, the combustion air temperature is raised by the heat of compression, and extraction feedwater heating would actually reduce the cycle efficiency by diverting steam from the lower pressure stages of the (steam) turbine. At the same time, less energy can be extracted from the flue gas since

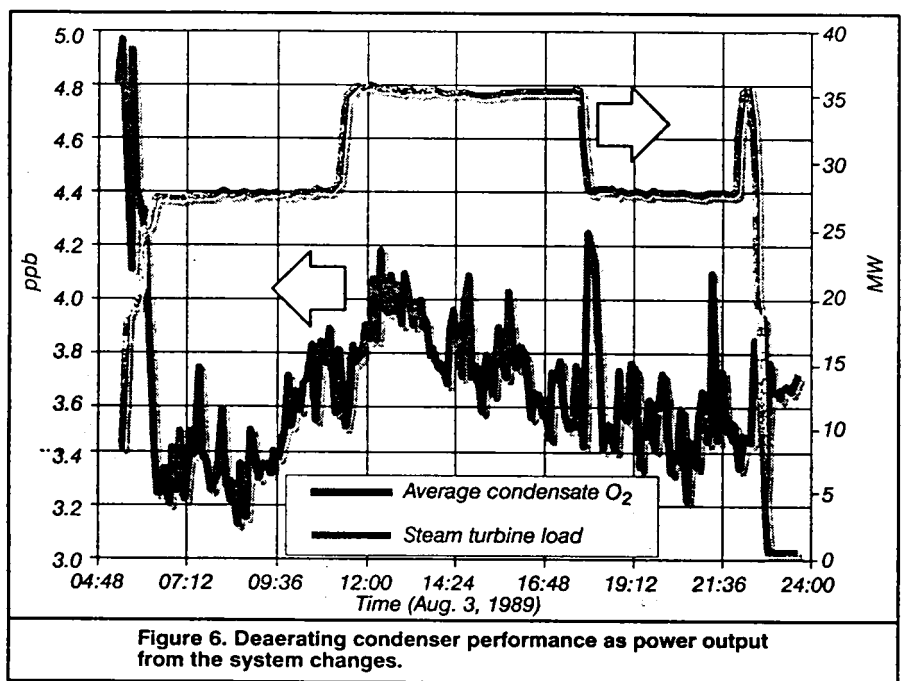


Figure 6. Deaerating condenser performance as power output from the system changes.

it would have to be discharged at temperatures above the feedwater entering the HRSG, since pressure deaerator feedwater temperatures are usually in excess of 230° F.

In the DO2 system, cold makeup water will be heated in the vacuum deaerator to the steam condenser saturation temperature using the waste turbine exhaust steam. In a conventional power cycle, this is accomplished with low pressure feedwater heaters where higher level extraction steam is used downstream of the surface condenser. This leaves the mixture of makeup water and condensate at the corresponding temperature. Unless the condensing temperature is very low, feedwater to the HRSG will be warm enough to preclude reaching the acid dew point temperature when clean fuels, such as natural gas, are used.

Dissolved oxygen levels at Gilroy have continuously measured below 7 ppb (Figures 4, 5 and 6). This is true despite part load operation and makeup water flows that can reach 85% of condenser flow. For more than two years, the plant has been required to shut down daily for six hours because of contractual obligations.

BENEFITS OF RETROFITS

The system can be retrofitted to existing power plants that encounter dissolved oxygen problems during part load operation, or that are required to shut down frequently. In this arrangement, the condensate leaving the vacuum deaerator will be warmer than that leaving the steam condenser.

A conventional power plant has no problem with this because feedwater must be heated before it reaches the boiler. However, in a combined cycle plant it is preferable to supply the HRSG with the coldest water possible (as long as acid dew point temperatures are exceeded). This improves the heat recovery in the HRSG. This is accomplished in the retrofit system described by flashing

condensate in a flash tank (not shown). Venting the flash tank to the main steam condenser cools the liquid to the same temperature as that in the condenser itself.

CONCLUSION

The statement in EPRI's report (NP-2249): "Present design practices and air removal systems do not deaerate condensate satisfactorily. Deaerated oxygen levels cannot be maintained at start-up and low load," is no longer correct. A number of combined-cycle cogeneration plants and several conventional power plants have proved that a new systems approach can control condensate dissolved oxygen to less than 7 ppb under any operating conditions. The resultant system reduces the cost and improves the efficiency of combined-cycle power plants when clean fuels are used.

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"Guide to the Design of Secondary Systems and their Components to Minimize Oxygen-Induced Corrosion," S.W.W. Shor, et al, EPRI Report NP-2294, March, 1982.

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