Proceedings of ICAPP '12
Chicago, USA, June 24-28, 2012
Paper 12001

KEEPING COOL WHILE PLANNING A MAJOR COOLING SYSTEM MODIFICATION FOR A LARGE BASE-LOAD POWER PLANT

Jeffrey Mallory[a,*], P.E., Raubin Randels[b], P.E., Jeri Penrose[a], Daniele Ludovisi[a], P.E., Ph.D.
[a] Sargent & Lundy LLC, 55 East Monroe Street, Chicago, IL 60603
[b] Sargent & Lundy LLC, 1860 N. 95th Lane, Phoenix, AZ 85037

[*] Corresponding author: Tel: (312) 269- 6712, Fax: (312) 269-7041, Email: jeffrey.s.mallory@sargentlundy.com

Abstract – *This paper addresses vital considerations which need to be addressed to help ensure that the wisest approach is used for evaluating or modifying existing open or closed cycle cooling systems.*

I. INTRODUCTION

A number of operating U.S. power generating facilities with closed cycle cooling systems (CCS), and also those plants with open cycle (once-through) cooling (OCS), are considering modifications to either modify or utilize closed cycle cooling in the future. Some of the characteristics common to these plants include:

- Aging equipment and materials resulting in cooling system performance and reliability deterioration.
- Increased cost and lessened availability of raw cooling water leading to new closed cycle systems to utilize higher cycles of concentration (COC).
- Decreasing quality of available water supplies.
- Compliance Requirements associated with §**316**(**a**) and §**316(b)** of the Clean Water Act that may result in the major plant modifications, including open-to-closed-cycle conversions.
- Cooling system performance problems from legacy issues such as initial under-sizing or failure to meet desired performance expectations.
- Power generating owner and operator desires for:
  - Power uprates (typically for nuclear units)
  - Unit life extension
  - Need for improved operating cost competitiveness

II. MAJOR MODIFICATIONS TO EXISTING TOWERS

In order to improve performance, existing cooling towers often undergo major modifications to tower fill, drift eliminators, fans and circulating water flow rates. This is due to the fact that cooling systems degrade with age and become less efficient, less capable, and more costly to maintain. There are several relatively minor tasks that can be undertaken to improve system performance, at least temporarily, that should be considered in lieu of complete replacement. These include:

- Regular maintenance;
- Mechanical or chemical cleaning;
- Adjusting fan blade pitch to increase airflow;
- Balancing of tower water distribution systems;
- Improve water makeup quality and operating chemistry.

More capital-intensive projects to improve existing system performance include:

- Installation of an online condenser cleaning system;
- Replacement of drift eliminators with lower pressure loss style and tower fill with more efficient and/or lower-clogging type;
- Replacement or upgrade of tower water distribution systems;
- Completely re-tube or restore plugged condenser tubes to operation;
- Increasing or restoring circulating water (CW) flowrate.

III. ADDING NEW HELPER TOWERS

Installation of helper towers to an existing closed cycle system requires a detailed analysis of the existing cooling tower design and operating characteristics. Addition of helper cooling in parallel with a natural or mechanical-draft cooling tower-cooled system enables a portion of the CW flow to be diverted which may significantly increase the performance of the existing tower.

It is also important to note that the addition of helper towers to a closed-cycle tower system must be handled carefully to ensure that sufficient water flow is maintained to the existing tower to preclude improper spray distribution and scale deposits. Addition of a helper tower to an open cycle system must consider the optimal means to supply the new towers with hot condenser discharge water. Because the helper tower is decoupled from the plant, there are potentially more options available for installation, although suitable real estate must be located to site the new towers and pumps economically.

Further complications of helper tower installation or tower modifications include selection of tower performance parameters such that future operation at higher condenser heat loads will be covered. This typically occurs with nuclear power stations planning to increase thermal power to support a planned uprate. Designing for a yet-to-be-finalized heat load requires estimating operating conditions supported by design in a manner to ensure that no undue limitations result which may affect planned or potential power uprate operation.

IV. CONVERSION OF A ONCE-THROUGH COOLING SYSTEM

Conversion of a OCS to closed cycle is typically among the most complicated major cooling system modifications. Depending on the geographic location of the plant, there may be a significant loss of summer generating capacity due to the warmer CW water from a tower vs. the historic supply temperatures previously attainable in open-cycle mode.

IV.A. OCS Conversion Considerations

OCS to CCS conversions typically have the following disadvantages:

- High capital costs;
- Reduced plant efficiency due to increased auxiliary load and high condenser pressure;
- Potential thermal derates due to inability of CCS system to maintain turbine backpressure margin during hot weather;
- Continued water consumption due to evaporation and drift;
- Noise and visible plume;
- Increased water chemical treatment and wastewater (blowdown) management.

Major advantages of conversion to CCS:

- Reduced withdrawal rates;
- Reduced entrainment/impingement of aquatic life;
- Reduced thermal discharge plumes;
- Increased effectiveness of chemical treatment resulting in less system fouling.

Depending on the environmental and municipality regulations, a hybrid wet/dry cooling tower may prove to be an optimal trade-off. In fact this technology can address many of the shortcomings of other types of cooling tower installations with the inherent cooling capabilities of wet towers and reduction of the visible plumes in the majority of atmospheric conditions due to the dry heat exchanger section.

IV.B. OCS Conversion Technical Aspects

When converting a plant from OCS to CCS, the following constraints are normally present:

- The condenser is already in place and has been designed for single pass operation and low temperature rise. For plants with a long anticipated remaining life and a high capacity factor, it may be appropriate to modify the condenser and the recirculating system in order to re-optimize the cooling system for a minimum life cycle cost. CW piping modifications to provide a double-pass arrangement are beneficial to develop a higher condenser rise to support efficient cooling tower operation. This requires routing of very large piping in extremely tight confines.
- With an increase in circulating water temperature due to CCS operation, the condenser performance is reduced and the backpressure on the turbine increased. Let's remember that the steam turbine was originally specified for a once-through cooling and, therefore, its design exhaust pressure is likely to be 1.5 in. HgA. In plants originally designed for CCS, design exhaust pressure is closer to 2.5 in. HgA. Therefore, given the site ambient conditions, it may be impractical or even impossible to achieve the design backpressure with a closed-cycle cooling system with the existing plant condenser and circulating water system.
- The addition of a cooling tower to the cooling circuit will often necessitate some extensive modifications to the existing condenser and

circulating water pumps and piping due to higher pressures and new piping layouts.

Although the conversion to CCS is a complex process, significant plant modifications may be limited to the addition of cooling towers, tower supply pumps and pump intake, and potential modifications to existing circulating water pumps and their pump houses. It may be possible to maintain existing condenser operating pressure relatively unchanged for the CCS if new tower supply pumps are utilized to supply the new tower in lieu of converting the OCS to a typical CCS with a completely closed loop with one set of CW pumps. Service water and CCS makeup flow would still be maintained through the existing intake structures. The new tower supply piping would need to be routed from new tower supply pumps to the cooling towers and back to the existing CW pumps. Depending on plant design, gravity-driven flow to the condenser from the cooling tower basin may be feasible and should be considered if possible to eliminate the extra tower supply pumps and still maintain relatively low condenser waterbox pressure. Therefore, the selection of the cooling tower location with respect to the plant may limit opportunities to simplify the conversion.

With the new CCS, the startup, steady-state operation, and shutdown operations would require modifications. Each safety-related system (for nuclear plants) requiring offline cooling would need to be reviewed and provided with secondary cooling. Additional security would also be required during construction within the protected areas.

IV.C. OCS Conversion Economics

Power losses in the winter months would be lessened but, during summer, the plant performance would suffer appreciably. In order to maintain current operational efficiencies, a drastic modification of the condenser would be required. However, due to the physical constraints of the turbine building, a significant size increase of the condensers is not typically possible without the complete reconstruction of the turbine building. A turbine building modification of this magnitude would be unprecedented in an operational plant and the costs associated with such a major modification would likely be cost-prohibitive.

V. REPLACING EXISTING DEGRADED TOWERS

Discussions with owners and operators of existing operating power generating facilities reveal that many are considering the replacement of existing towers, the addition of a new cooling tower(s) (open-cycle conversion), or the installation of helper towers to supplement an existing closed cycle tower.

The decision to replace an existing tower with a new tower may be initiated as the most straight-forward scenario. However, insufficient pre-decision analysis and evaluation often results in a process which becomes biased and ineffective. For example, for large base load power plants, a common occurrence (perhaps positive or maybe not) is to have to perform tower demolition and re-construction with the unit(s) on-line due to a restrictive plant outage schedule. Also, some projects may require temporary and final configurations. Each scenario must be fully evaluated to ensure continued safe and economical system operation.

VI. ENGINEERING AND OPERATIONAL CONSIDERATIONS AFFECTING THE FINAL DECISION

VI.A. Impact to Plant Systems

It is possible to develop a comprehensive list of impacts and considerations in which a new cooling tower installation may affect a given plant. Areas that need to be evaluated to determine potential impacts to existing plant systems, including those that will require extensive outages to enable project installation, include:

- CW system components;
- Auxiliary power system;
- Fire protection system;
- Existing underground utilities;
- Transmission lines (affected by potential winter icing);
- Makeup water treatment;
- Chemical treatment ;
- Discharge water treatment.

VI.B Understanding Existing Operating Conditions and Plant History

One common source of data in operating conditions and plant history can be found in historic plant maintenance work orders. For the nuclear industry, a compilation of plant issues from many stations can be easily accessed via the EPRI database. Lessons learned are applicable to fossil units and are often available from consulting engineers and owners for previous projects. It is important to review these sources to identify areas of concern to enable pro-active steps to be taken during the cooling system modification to minimize the potential for problems in the future. For example, common causes of fouling and degradation of cooling systems include:

- Insufficient chemical treatment due to inappropriate treatment regimen that may be related to strict discharge permit limitations, low-grade makeup water, or lack of treatment discipline. This may cause biological fouling, scaling, or corrosion.
- Operation at excessive COC.
- Poor/variable water makeup quality.

VI.C Assessing Water Availability

Power plant cooling systems consume large quantities of water. As the plant owner, the cheapest and highest quality water source is always desired. However, operating plant permits may limit water source availability and thus scarcer, non-conventional sources of water makeup must be considered. On-site water storage via ponds or reservoirs may be warranted as a least-cost option. Sources of makeup water include:

- Blowdown from existing water users such as the main cooling tower or water treatment reject streams;
- Ground water;
- Surface water (rivers, lakes, canals, municipal reservoirs);
- Grey water from municipalities or industrial users;
- Seawater;
- Use of dry cooling to lower or eliminate water demand for new cooling loads.

These makeup water sources usually require different cooling system designs to prevent scaling, corrosion, or fouling. Therefore, the cheapest source may not prove to be the most economical selection.

VI.D. Optimum Cycles of Concentration

A water availability evaluation is closely tied with the optimal cycles of concentration and makeup water pre-treatment regimen determinations. Also, the quantity of makeup water needed by a new cooling tower is influenced by site ambient conditions, the heat load to be rejected in the tower, and the selected COC. If water is scarce, operation with higher cycles of concentration can reduce water usage. However, the savings realized from utilizing less water must be compared to the higher costs of the tower and cooling system designs that are capable of tolerating the increased demands. Higher cycles of concentration may result in use of more expensive materials of construction, more forgiving/less efficient cooling tower fill which requires a larger tower, an increase in auxiliary load, increased maintenance, and more demanding control of water chemistry. A detailed study can identify the cost-optimized water source and COC when more than one potential source of makeup water is available. An optimization analysis may determine minimal cooling system operational requirements as well as maintenance costs while ensuring a design that is flexible and reliable.

VI.E Water Chemistry

Cooling water chemistry is an important factor in determining the scope, budget, and schedule for changes to the circulating water system so it needs to be addressed as an integral part of the planning stage. CW chemistry is determined by makeup water composition, operating cycles of concentration, particulates and gasses scrubbed from the air, and treatment chemicals added to the system.

The chemistry determines design requirements for the following:

- Cooling system materials of construction;
- Cooling tower fill type;
- Makeup and blowdown pumps and piping;
- Makeup water pre-treatment and/or sidestream treatment;
- Treatment chemical storage, feeding, and control facilities;
- Blowdown de-chlorination or molluscicide detox.

Cooling water chemistry also affects the following evaluations:

- Particulate emissions from drift;
- Discharge NPDES permits;
- Control room habitability.

It is important to characterize the chemistry of water supplied as makeup as accurately as possible.

The composition of makeup waters can vary from season to season and from year to year, particularly if sourced from surface waters. At least one year's data is needed to encompass seasonal variation and several years of data are generally needed to bound makeup chemistry conditions. These data can usually be obtained from EPA and USGS stream quality databases or from historical plant records, but a supplemental monitoring program is sometimes necessary. Design based on insufficient historic data can cause major operational problems in the future.

VII. SELECTION OF NEW COMPONENT CONFIGURATION, DESIGN MARGIN, AND LOCATION.

Detailed evaluations are fundamental to support development of the correct configuration and technology(ies) to address a new or revised plant cooling requirements. Evaluations must develop feasible opportunities for optimization via alternatives comparison studies and net-present-value estimates. Identification of various alternate modifications, and/or implementation of strategies, that can substantially lower the required capital expenditure and operating costs, and still accomplish the project goal is the objective. Often such confirmatory evaluations are not part of a utility's skill set and a team of qualified and experienced specialty personnel is engaged. Such an evaluation should consider the following topics to develop the basis for alternatives comparisons to establish the optimized solution for each generation asset:

- Design pressure and temperature ratings of CW pipe and condenser waterboxes;
- CW pump capability;
- Quantification of potential derates for the existing system and proposed options;
- §316(a) and §316(b) compliance;
- Particulate emissions (from drift losses) and New Source Review;
- Existing component conditions, capability, and remaining life;
- Siting of new system components and connecting piping;
- Potential tower plume and fogging impacts;
- Icing potential of nearby roads, switchyards, or power lines;
- Existing buried structures;
- Substructure / foundation design;
- Construction material selections – tower skin, tower fill, mechanical fasteners, concrete composition, rebar, piping, valves;
- System redundancy / availability requirements;
- Auxiliary power availability and requirements;
- Maintenance implications;
- Installation of features to allow on-line maintenance vs. limiting maintenance to outages;
- Necessary modifications to existing infrastructure, including plant security access control for construction activities as well as final installed configuration;
- Project scheduling of major activities;
- Risk evaluation of evaluated options;
- Contracting strategy;
- Capital budget.

VIII. ALTERNATIVES COMPARISON STUDIES AND NET-PRESENT-VALUE ESTIMATES

Perhaps the most important aspect to understand with respect to large cooling system modifications is the recognition that a balanced, properly weighted approach is far more likely to result in success, versus a simple, incomplete approach which may cost less to perform. It has been our experience that a fundamental aspect of a good analysis will challenge existing data and proposed solutions. Verification of existing system design with regard to adequacy is vital in order to avoid the trap of simply replicating an inadequate design. For example, it may be unwise to base new modification goals on original flowrate, temperature rise, etc. design criteria. There are several specific alternatives comparison studies that are typically applicable to cooling system optimizations required for new tower installations including:

- Tower sizing and configuration (utilizing input from the derate analysis discussed below).
- Installation schedule (considering predicted plant derates for various options).
- Potential upgrades or modifications to existing components (utilizing input from the derate analysis). This should include consideration of CW pump and chemical treatment modifications, condenser upgrades, and steam turbine overhaul or major upgrades. Specifically for OCS to CCS conversions, the existing CW system components must be carefully evaluated. Consideration must be made for upgrading or re-rating existing components to utilize a single CW cooling loop or, alternatively, use of a two-loop system where the free-flowing hot discharge from the condenser is pumped by a new set of tower

supply pumps into the new cooling tower, with the cold water from the tower directed to the existing open-cycle pumps (after isolating the pumps from the original cooling body). The latter option is less efficient, but allows the existing CW system and condenser to be utilized without major modifications and may be significantly more reasonable to implement.

- Water availability study and tower cycles of concentration optimization.
- On-line condenser cleaning systems (chemical and ball-tube).
- Contracting strategies.

The evaluation of a CCS should be performed by using a state-of-the-art computerized simulation tool that can accurately predict the plant performance and provide operational parameters and power reductions.

OCS to CCS conversion would introduce both operational efficiency losses associated with operating beyond the original condenser design conditions and parasitic losses associated with the operation of the circulating water pumps and cooling tower fans and booster pumps. Such analysis would also help determining if an extensive improvement to the electrical distribution system would be required due to the expected electrical parasitic losses. Operational power losses may account for a loss in net electrical power generation around several MWe and would peak during the warmest temperature and highest humidity conditions, when electricity demand is at its highest. In fact, the performance of any CCS is primarily driven by the ambient weather conditions at the site, particularly via the cooling tower approach to seasonal/daily wet bulb temperature.

The optimization of a CCS is more complex than it is for once-through systems and several trade-offs are available:

- For a given circulating water flow rate and condenser, the size and cost of a cooling tower can be optimized against the yearly plant derating.
- For a given tower approach, the tower size can be optimized against tower fan power.
- A higher circulating water flow rate will reduce the range and permit either the condenser, the cooling tower or both to operate at higher approach/TTD for reduced capital cost.

IX. SCOPE IDENTIFICATION AND CONTRACTING

A complete cooling tower replacement, addition, or modification scope definition is the direct result of a detailed evaluation process. Once the evaluation of alternates begins, the scope definition process will follow. Upon the completion of each evaluation step comparing several options, items can be deleted, added, or further refined. With a proper scope, it is possible to develop an accurate project schedule and cost estimate for the selected modification option. The scope definition sets the complexity and ultimately decides the success of the project. If scope is sufficiently clear, the likelihood of cost over-runs and/or performance shortfalls upon completion of the modification is significantly reduced. Also, it is important to note that scope definition must be a collaborative effort among the design-engineer, plant owner, construction contractors, and any vendors selected to support modifications of existing components or supply of new components. It is the design-engineer's job to tie the input from each of these entities together such that the project can be executed with high quality deliverables, on-time, on-budget, and meeting but hopefully exceeding client expectations.

Once the scope is defined, the contracting strategy can be selected. The optimum strategy will be highly dependent on the nature of the selected modifications and the owner's capabilities and preferences. The work may favor single lump sum, turnkey projects, EPC contracts, or multiple contract approaches.

IX.A. OCS Conversions

Some activities can take place before the actual construction and with the plant online producing energy. However, due to circumstances such as close proximity of several construction activities to nuclear safety-related equipment and the impact on equipment necessary for power generation, certain activities may require consecutive extended construction outages thus causing significant losses in revenues. Therefore, while assessing if an OCS to CCS conversion is actually economically feasible, the following aspects need to be considered:

- Initial capital costs;
- Cost associated with material disposal and possible radiologically contaminated material bonification;

- Construction outage lost electrical generation;
- Lost electrical generation due to new condenser operating parameters;
- Lost electrical generation due to parasitic losses;
- Operation and maintenance costs, including water treatment costs.

Furthermore, OCS to CCS conversion process may take several years and the change in interest rates may be a significant game changer.

Therefore, system optimization to minimize total life cycle cost involves the trade-off between cooling system capital cost and future operating and penalty costs. A larger, more effective cooling system costs more initially and may consume more power in operation but will provide higher plant efficiency and generating capacity over the life of the plant. Conversely, a smaller, cheaper cooling system will incur higher operating and penalty costs. To carry out a total evaluated cost optimization, the following information is required.

- Annual wet bulb temperature curve;
- Turbine heat rate curve;
- Value of power ($/kW);
- Assumed plant life and capacity factor;
- Inflation/amortization factors;

A cost/benefit analysis can be performed to find a global minimum and determine the optimized cooling system. Therefore, the thermal performance of the cooling system is not the major player in the final selection of the optimum choice.

X. DESIGN PARAMETER DEFINITION

For the development of any large capital project, the ultimate goals of the project must be clearly defined up front. Such input needs to come primarily from the owner, but the engineer performing the evaluation must also know what input is truly needed and the appropriate questions to ask. It is the engineer's duty to collect data to establish the existing plant capacity and identify potential alternatives for evaluation. It is imperative to approach the evaluation without pre-conceived notions that have no physical basis. For example, cooling system performance is too often gauged on the preceding summer's operation. For instance, suppose that there is an unseasonably hot summer and the plant is forced to thermally derate the unit resulting in revenue loss. A common response is to assume that the current cooling system is severely degraded and the decision is made to design a new cooling tower to eliminate all future derates so that there is no lost generation in the future. On the other hand, when an exceptionally cool summer comes along, a false sense of security is fostered that the cooling system is actually in better shape than it is. Truly, only a detailed plant derate study can identify a cost-optimized scope for a new tower modification. A derate study considers many factors and the inputs typically required include:

- Several (10 or more) years of historic weather datasets to allow projection of cooling tower performance.
- Historic station data on cooling system performance and/or performance tests of towers, circulating water pumps, condensers, and also the low pressure steam turbine.
- Maintenance histories (via review of plant documentation).
- Recent evaluations of current cooling system performance.
- Plant operability limitations (turbine backpressure limits, vacuum system capability, water usage restrictions, etc.).
- Actual or anticipated permit limitations.
- Project financial inputs (required ROI, financing interest rates, etc.)
- Value of electrical power, preferably on a monthly basis.

X.A. Quantification Potential Derates

While it is likely that the original design of the unit was based on avoiding all lost generation capacity due to plant derating (physical power reduction of the boiler), it is unlikely that the optimum solution to a cooling tower addition or modification is as simple as installing a new tower designed to the original specifications. Derating can become necessary for reasons such as high steam turbine backpressure (due to turbine and/or cooling system degradation, increased heat loads, or air removal system malfunctions), lowered thermal discharge permit limits [i.e. §316(a)], or other equipment capability limitations (likely due to equipment degradation or operation above equipment capabilities). Thus, a detailed derate study should be performed to assess and estimate existing and future plant operation and economics considering all proposed solutions. The results of the study will provide a basis for establishing and optimizing overall plant operation and profitability. A common mistake is to design the new cooling tower to eliminate all derates. This approach will result in a tower that is substantially larger than required which may kill the project outright due to the increased cost estimate. It will also increase maintenance and operating costs over the life of the tower. A derate analysis can identify key plant components or activities that, with relatively minor investments, can result in improved generation at lower cost and complexity.

X.B. Noise Considerations

While not all cooling tower additions require special noise abatement considerations, there are occasions when the available location for new towers are located such that the tower noise must be kept to a minimum to meet permit limitations or ensure "good neighbor" practices to the surrounding community. Options to lower tower noise include:

- Low speed, low-noise fans;
- Single-side air inlet design;
- Acoustical inlet louvers;
- Strategically-placed noise reduction walls adjacent to the tower inlets.

X.C. Risk

With every major project of the magnitude involved in cooling system modifications, there is risk. However, depending on the quality and depth of the up-front engineering and design, this risk can be identified, quantified, and mitigated.

One specific area of risk on any large capital project involves capital expenditures to implement the design. Several issues that impact the economics of such projects include the following:

- Duration of regulatory agency interactions (federal, state and local licensing).
- Uncertainty surrounding the large volume of uncontaminated and radiologically contaminated spoils and construction debris disposal.
- Construction delays due to the possible disturbance of tritiated groundwater pathway.
- Impacts of increased plant security and the necessary construction equipment access.
- Unpredictable weather phenomena.

XI. CONCLUSIONS

Substantial experience and expertise in the power industry on this topic is available. It would be unwise for a power plant owner and/or operator to not avail themselves to readily available industry knowledge to undertake such an important project.