Evaluating Cooling Tower Upgrades

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When considering improvements to cooling towers, it's important to perform an economic analysis of the options.

When planning and evaluating a cooling tower repair and maintenance program, few cooling tower owners and operators conduct a thorough economic evaluation. As a result, requested repairs and upgrades are frequently deferred in favor of allocating maintenance dollars to other projects.

In the past, most chemical process industries (CPI) plants relied on once-through cooling, drawing cooling water from a local source or a man-made pond. The temperature of the incoming water depended on environmental factors and was not controllable.

To a certain degree, this is still true in a closed-loop system with a cooling tower. Once the maximum water flow and air flow are achieved, nothing more can be done to reduce the cold water temperature — placing the plant operators completely at the mercy of ambient temperature conditions. Many, therefore, overlook the productivity gains that could be achieved by upgrading their existing system. Years of experience led them to believe that the plant just operates at reduced capacity/efficiency on those hot summer days and there is nothing that can be done about it. The opposite is usually true.

Industrial cooling towers routinely last 20 to 30 years, sometimes longer. Compared to the state of the art when these towers were designed and installed, today's technology can deliver significantly colder water with the same basin footprint and even lower pumping head. Other articles have focused on identifying physical and performance deficiencies in existing cooling towers and offered advice on correcting them. While simple repairs and modifications can be done at minimal expense, more-extensive cooling tower maintenance projects require proper planning and economic justification. A poorly executed economic evaluation can result in deferral of cooling tower maintenance and cost millions of dollars in lost productivity.

A thorough economic analysis and justification for proposed cooling tower repairs and upgrades should include the following basic steps:

1. assess the existing tower thermal performance versus the design thermal performance
2. model the response of the process to changes in thermal performance
3. assess multiple repair and upgrade scenarios to develop an optimized solution
4. complete a financial optimization analysis of the proposed solutions.

Costs associated with unplanned and catastrophic failure are not normally captured in this approach. Therefore, older cooling towers with significant structural or mechanical degradation should be addressed more urgently to mitigate the risk of unplanned outages. Additionally, some required maintenance items, such as mechanical equipment inspection and repair and structural refurbishment, are required for continued safe operation of the tower and are not expected to deliver improved thermal performance of the system. The analysis described here does not apply to those situations, and is only applicable where a thermal performance improvement is desired.

1 Assessing thermal performance

Most cooling tower engineers would say that the only way to truly measure a tower's thermal performance is to conduct a performance test. While this is true, the performance trend of a tower can be assessed with generally available process data. Cooling tower thermal performance is demonstrated by plotting the outlet cold water temperature vs. the inlet wet-bulb temperature at a constant fan speed, water flowrate and heat load.

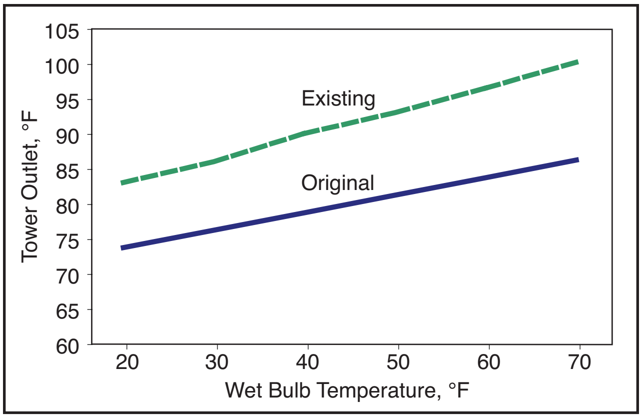
Every cooling tower is designed to deliver a specific outlet temperature at a design combination of wet-bulb temperature, heat load, water flowrate and air flow. This temperature, at the design point, may be around 80–95°F. However, this temperature would be expected only at design conditions, which are normally chosen conservatively and as such occur less than 200 h/yr. Thus, when reviewing operating data, one should expect to see temperatures below this design point for all except the hottest days of the year. If not, then the thermal performance of the tower may not be adequate.

An inspection and assessment by a local cooling tower specialist may help identify possible causes for the performance deficit. Typical causes include reduced (or increased) water flow through the system, increased heat load above design conditions, fouled or underperforming fill media, or various conditions that reduce the air flow to the system.

Two common causes of performance degradation in existing towers are poor distribution and improper water flow across the fill media, and changes in system design that result in water flowrates in excess of the original design. An inspection of the water distribution system should be performed to identify clogged or missing nozzles. Flowrate determinations can be made with non-invasive portable instrumentation, which provides an order-of-magnitude assessment of whether the system flowrate is consistent with the original design.

If the water flow is adequate, fill fouling may be the cause of reduced performance. Routine visual inspections should be performed to assess the level of fouling in the fill media. Extremely fouled fill media require cleaning or replacement. Fill cleaning is generally not a do-it-yourself activity. Once the scale and debris are removed from the fill, special care should be taken to extricate those from the system to prevent large particles from circulating through heat exchanger tubes or back to the cooling tower nozzles, where significant damage and flow blockage can occur.

Determining actual heat load on the tower is more difficult. Although the calculation is very simple — the water flowrate multiplied by the specific heat of water multiplied by the temperature differential — the actual measurement of temperatures and flowrates can be challenging. Using pump curves to predict actual flow rarely produces good results. Various instruments for estimating flowrate are available, but none are accurate enough to produce a reasonable heat load calculation. Most cooling systems are equipped with taps for Pitot tubes or other flow detectors. Installation of properly calibrated flow-measurement instruments remains the most reliable means for measuring flowrate.



■ Figure 1. A cooling tower specialist should compare the current tower performance to its original design performance.

Based on operating log reviews and system inspections, the cooling tower specialist should generate an estimate of the tower's current performance curve, such as the plot of current estimated performance vs. original design performance in Figure 1.

In some cases, uncertainty about actual flow and temperature conditions warrants a formal cooling tower thermal-performance test. These tests involve the installation of high-accuracy gages and instruments, and are useful for capturing a very precise snapshot of the system's thermal performance. Numerous companies provide this service at a cost anywhere from $5,000 to $15,000. Because of this expense, cooling tower performance tests are rarely conducted when evaluating maintenance and upgrade projects.

The need for a formal performance test is determined based on several factors. In general, the less temperature and flow data available from installed instrumentation, the more likely a formal performance test will be required, regardless of the tower's age.

Even new towers are unlikely to perform at design levels. According to the Cooling Technology Institute (CTI), only 58% of newly constructed cooling towers passed their initial performance test in 2007. While CTI does not publish the pass/fail statistics for individual manufacturers, every company knows its own pass/fail ratio and will usually disclose this information if requested. Since the failure rate of new towers is so high, it is advisable to always insist on a tower performance test when purchasing new equipment.

When evaluating system modifications such as nozzle change-outs, fan modifications, fill modifications or louver/air flow changes, the cooling tower maintenance provider should always give an estimate of the new cold water temperatures that will result from the maintenance. This will allow the value and payback of these projects to be determined.

Although performance assessments and tests provide useful technical information, they are void of economic analysis and do not detail what the cooling tower is capable of doing. For the economic portion of the analysis, the process that is receiving cold water from the tower must be evaluated and modeled.

2 Process response modeling

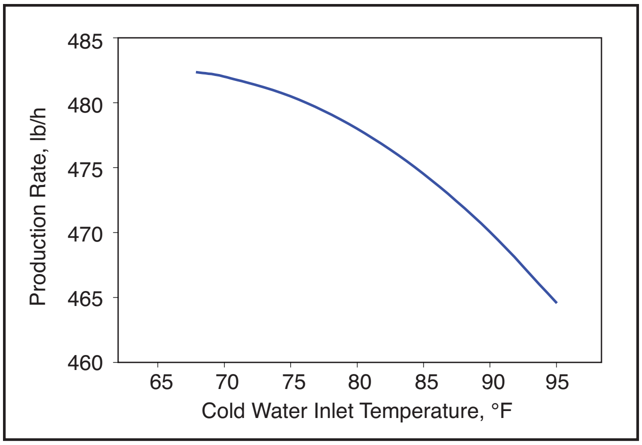
The second step of the evaluation process is to determine whether colder water will have a predictable and measurable economic impact on plant performance. An order-of-magnitude impact can be determined by asking "is there a difference in plant capacity or operating cost in the summer versus the spring or winter?" If the answer is yes, then some temperature-sensitive processes are probably being impacted by cold water temperature (*e.g.,* condensing processes, multi-stage compressors and steam turbines). Simple regression analysis of operating data can be performed to generate a mathematical function that expresses operating cost or output in terms of cold water temperature. At many plants, this analysis has already been completed. The engineering challenge is to use this knowledge to discover ways to improve plant economics.

This step becomes complicated when multiple processes rely on a common cooling loop, as is frequently the case in CPI facilities. One or two processes may be very temperature-dependent, a few may have minimal temperature dependency, and some may be relatively insensitive to temperature. In such cases, evaluate the most critical or temperature-sensitive process first. The best solution may be to split the cooling loop and provide the coldest water to the part of the plant where it is most valuable.

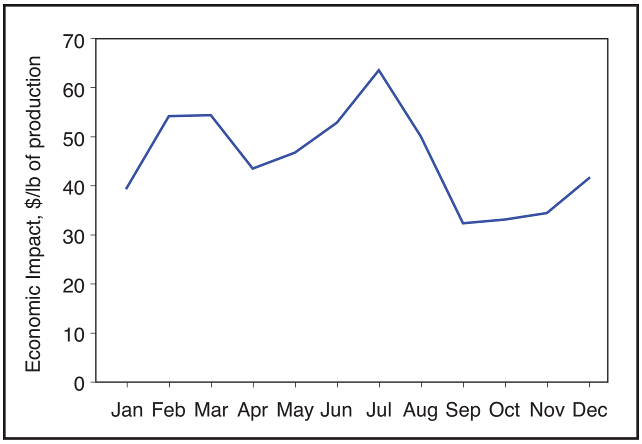
For each temperature-dependent process, a curve of performance vs. cold water temperature should be generated. Performance can be expressed in terms of product output, power usage, or any other key performance indicator relevant to the particular process. Depending on the cost variance, a separate curve is produced for economic impact vs. system performance. For example, if the key performance indicator is power consumption of a large electric-motor-driven compressor, then the economic impact will be driven by the cost of electricity. Since the cost of electricity may vary by season and by year, the economic impact needs to be plotted seasonally. Figures 2 and 3 are examples of key performance indicator and economic impact plots taking seasonal variability into account. In Figure 2, process capability is represented in terms of pounds of product produced per hour vs. cold water inlet temperature. The economic impact per pound of production is shown throughout the year in Figure 3.

This cold water for this process comes directly from the cooling tower. Thus, cooling tower performance can be directly coupled with production process performance.

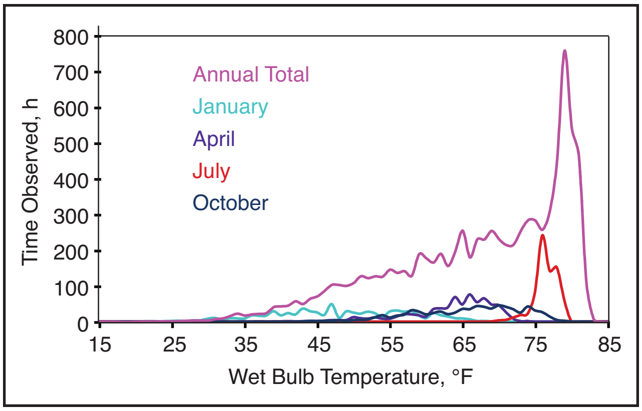
Once the performance vs. cold water temperature relationships are established, the next step is to determine what can be done to improve system performance and by how much.



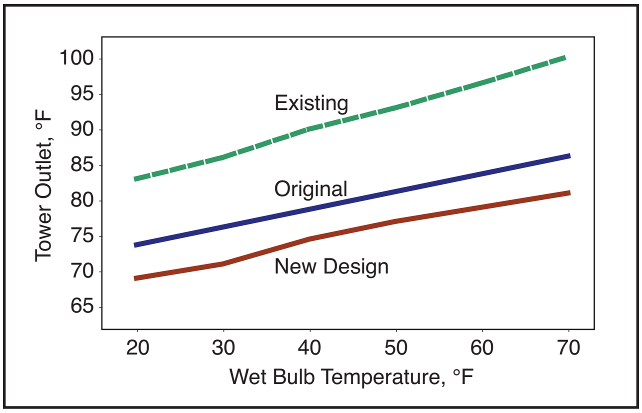
■ Figure 2. Process output is affected by seasonal variablility of cold water temperature.



■ Figure 3. Cost of electricity may vary throughout the year and affect economic impact.



■ Figure 4. Data from the National Weather Service can be obtained to produce annual and seasonal weather curves.



■ Figure 5. Comparing operating curves allows for selection and evaluation of multiple new tower options.

3 Predicting and evaluating thermal performance improvements

Annual weather variance needs to be added to the curves generated in the first two steps (existing thermal performance, process impacts and economic impacts) to develop a comparative model that predicts financial impact and payback for various cooling tower upgrade projects.

The first comparison is usually between the "as-is" performance curve and the original design performance curve, quantifying the financial impact of the performance degradation. For example, a 25-year-old crossflow tower with splash fill in need of work may have an observed cold water temperature of 98°F (at 68°F wet-bulb) and an original predicted cold water temperature of 85°F. This is depicted in Figure 1. Therefore, while the tower was designed to deliver 85°F water in this weather, performance degradation has caused the cold water temperature to increase by 13 degrees, to 98°F. If this tower is cooling a temperature-sensitive process (as illustrated in Figure 2) the higher water temperature reduces the productivity of the process. Of course, this example considers only a single wet-bulb condition (68°F). In order to fully assess the impact of the higher temperature on process operations, the system's response under all observed conditions needs to be evaluated.

Figure 4 illustrates the average annual and seasonal distribution of ambient wet-bulb temperatures at a particular location. Such data are available from the National Weather Service for hundreds of weather-data collection centers. The x-axis shows the observed wet-bulb temperature, and the y-axis represents the number of hours that each temperature is observed in the time period.

In some cases, a simple evaluation based on the annual sum of each wet-bulb temperature may be sufficient. If the facility makes a product that is sensitive to seasonal price fluctuations, it is more appropriate to run seasonal performance models that take into account the differences in produced (or consumed) commodity prices. In cases where the cold water temperature affects the power usage or generation of a plant, it may be appropriate to evaluate changes in temperature during the day vs. at night. Weather-data software packages that provide observed temperature statistics in 3-h time increments are available, making this level of analysis possible.

By combining the tower performance curve, process performance curve, economic impact curve and annual weather curves, the economic value of restoring the tower to its original design condition can be predicted.

Next, the technical options for restoring the tower, such as fill media replacement, water distribution system refurbishment, or enlarging the tower to compensate for increases in flow and heat load, need to be identified. More importantly, the impact of complete system replacement needs to be evaluated. For example, the under-performing 25-year-old crossflow cooling tower may be replaced with a modern counterflow tower containing high-efficiency, low-clog fill, reducing the cold water temperature even further with the same footprint. This improvement can result in an additional 5–10°F of cold water temperature reduction with no increase in electricity consumption.

Figure 5 compares the new operating curve to the as-is and original design curves. Selecting and evaluating a replacement tower normally involves multiple iterations to properly optimize the selection.

4 Financial modeling and optimization

The total economic impact of each option is calculated and ranked for each iteration. Traditionally, the selection of an "optimized" cooling tower was merely one that balanced the initial cost vs. operating cost of a cooling tower based on continued operation at its design

Table 1. Financial measures should be used to evaluate cooling tower options.

Option	1	2	3	4	5
Capital Cost	$1,330,000	$3,300,800	$3,675,000	$6,400,800	$2,000,000
Simple Payback, yr	0.19	0.46	0.38	0.70	0.28
10-yr NPV	$47,128,886	$46,880,905	$62,883,706	$57.808,694	$48,352,251
5-yr IRR	526%	218%	260%	142%	363%

point. Such optimization models do not consider the impact on process operations, nor do they consider operations above or below the design conditions. The integrated model presented here, which considers the entire range of weather and operating conditions, allows a more-precise optimization to be performed.

The overall value equation for comparing cooling tower installations should generally include:

- capital costs for equipment and installation
- electricity costs for fan and pump operation
- water treatment costs
- maintenance costs (this is especially important for comparing a new tower scenario vs. a repair/refurbish scenario)
- operating cost reductions due to lower operating temperatures
- increased revenue or output resulting from lower operating temperatures.

The first step in performing this optimization is to determine what financial measure will be optimized. This requires engineers and plant personnel who recommend equipment purchases and upgrades to understand the company's evaluation criteria for ranking and approving capital projects in order to present a properly optimized solution.

One method of evaluating projects is to set a requirement based on simple payback. Simple payback is a very-short-term measure of a project's return (the time it takes for the investment to pay for itself), and is calculated by dividing the total capital expense by the annual economic impact. Simple payback is a screening tool used primarily in constrained environments, and is rarely used as the primary metric for ranking and evaluating capital expenditures. More common measures, such as internal rate of return (IRR), net present value of cash flow (NPV), and economic value added (EVA), provide more meaningful descriptions of a project's long-term value. However, experience has shown that a project option that optimizes one measure, such as 10-yr EVA, might not be the best option when measured in terms of IRR. For this reason, it is crucial to take the appropriate financial metric into account when performing a system optimization.

Table 1 summarizes the results of an evaluation of five different cooling system options for a gas processing facility. The first three options involve supplying supplemental cooling by adding one or more cells to the existing system, the fourth option a conversion of the existing tower to a counterflow design to lower both the cold water temperature and power usage, and the fifth option a combination of supplemental cooling and fill replacement of the existing tower. Option 1 had the shortest simple-payback period and highest 5-yr and 10-yr IRR, on a discounted cash flow basis, while Option 4 has a higher 10-yr NPV. Thus, the "best" solution will be determined primarily by the financial results that are desired — a quick payback, or maximum long-term value.

Combining cooling tower and process expertise

Because of the close interaction between cold water temperature and process performance, it is critical that cooling tower upgrades and repairs be planned and evaluated with a thorough understanding of cooling tower design, process operations and financial metrics. While there are plenty of tricks and fixes that can make things operate a little better or get through one more season without spending any money, many cooling tower enhancement projects have significant financial benefits, and delaying certain repairs and upgrades could be costing the plant millions of dollars in lost productivity and excessive operating costs. Engineering is an economic exercise with a basis in science. While the science of cooling tower operations is very simple and well-understood, the economic analysis requires rigor and discipline to guarantee that capital and maintenance dollars are generating the desired returns. CEP

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