In Hot Water: A Cooling Tower Case Study

INSTRUCTOR'S MANUAL

Justin Cochran, P.K. Raju, and Chetan Sankar
Auburn University

Case Overview

At Plant Vogtle, managers and engineers are faced with two alternatives in attempting to improve performance of their counterflow natural draft cooling tower. The source of the tower malperformance seems to be in the water distribution across the tower's area. In areas with improper distribution, cold air can rush through the tower and fail to perform its job of transferring heat from the hot water.

Vogtle depends on their natural draft cooling towers to remove heat from the power cycle. Depending on the efficiency of the towers, the cycle can realize more or less power output. When the unit was put into operation during 1989, the efficiency was 76%. In order to increase the efficiency of the tower to 100%, the plant implemented several modifications of the cooling tower water distribution pattern including one in 1990. This modification, made by the manufacturer, resulted in an efficiency of 91%. In attempts to further increase the tower's efficiency, a cooling tower consultant, John Cooper was hired to suggest modification for the cooling tower distribution pattern. Cooper's recommendation in 1995 resulted in a decreased efficiency to 86%. In 1998, his second attempt at modification resulted in an efficiency of 79% resulting in a greater loss of revenues for the company. During 1999, Cooper had come up with a new modification to the water distribution system that he expected would increase the efficiency from 79% to 100%. The management had to decide between the two options: revert back to the best design so far that resulted in 91% efficiency or implement the new modification that might increase the efficiency to 100%.

Water distribution is controlled by plastic nozzles of particular diameters which limit flow to a certain flowrate. By varying zones of the different nozzle sizes across the tower, more or less hot water can be released in different regions. The tower uses around 10,000 nozzles to control the distribution pattern, and this pattern has a direct effect on the efficiency of the tower. By releasing too much water in some areas, air flow may be stifled resulting in less heat transfer. On the other hand, if too little hot water is released in some areas, regions of cool, dense air may pass through without cooling as much water is it could. It is the balance between the two that results in the best performance. However, this doesn't necessarily mean that water should be uniformly released. For a tower of this size, the air is preheated as it travels from the edge of the tower to the center, reducing the temperature separation between the air and the water, and hence reducing heat transfer. This is what leads to having different nozzle sizes and regions, trying to optimize cooling across the entire tower.

Increasing the tower's efficiency from the current efficiency of 79% to 100% would result in more plant output (5-7 MW), a cost impact of over $3 million during the remaining 30 years of expected plant life. The cost of the modification is close to $100,000.

The managers and engineers are at the decision point. They can either choose to revert to the known configuration that results in a tower efficiency of 91% or choose to modify the tower based on John Cooper's new recommendation. The students will take the roles of these managers and engineers and try to determine from the information given which modification will be the most beneficial to the plant.

Educational Objectives

The educational objectives of this case study are:

1. Bring cooling tower design issues from the real-world to classrooms.
2. Integrate engineering topics such as thermodynamics, heat transfer, evaporative cooling, and cooling tower design with business topics such as decision making, financial assessment, project management, and risk management involving the design of a cooling tower.

Discussion

There are several considerations that the student must be aware of before making their modification decision. The first consideration is that cooling tower modification is considered to be as much an art as a science. This has led to some of the difficulty that the Southern Company has faced

* Mechanical Engineering Department
** Management Department

during this decision. John Cooper, who has had great successes in other tower modifications, is one of the experts in this field. Even though his past modifications at Plant Vogtle have been disappointments, this modification (with his supporting evidence) may be effective.

The discussion of John Cooper's reputation and the uncertainty associated with tower modification is emphasized to demonstrate that there is obviously some risk in choosing the alternative that he has presented. First, the prior decreases in performance from John Cooper's modifications, regardless of his other successes, has brought his credibility into question. Also, by his own admission, the modification suggestion he is presenting is an adjustment of tower conditions he has never encountered. It has a scientific basis, but does contain some guesswork. If John Cooper is right, the cost benefit of increased performance can be greater than that of reverting to the 91% solution. Therefore, an assessment of the financial risk of this alternative must be evaluated.

The 91% alternative provides a guaranteed performance. It is below the tower's expected capability, but will be successful to a known extent. The risk of this alternative is virtually non-existent. However, the long term cost benefits will not be as great.

The student should realize that there is an incremental difference in the long term cost benefits of the supposed modification performance increase and the performance of the tower at 91% (the actual modification costs will differ in parts costs, not labor). The student will realize that there is no guarantee that the new modification will result in an increase in efficiency at all. In fact, a decrease could potentially occur. Also, the new modification may reach any efficiency between 79% and 100% (supposing an increase), therefore a reduction in the expected incremental cost benefit may occur. (If the tower performs at 92%, is it worth the risk?)

Students should also realize that the new modification can be made at this point and if it is not better than the 91% achievable using the previous set-up, then the modification to the 91% configuration can be made 18 months later. There will obviously be greater costs for making two changes, but the students may decide that since the changes do not have to be permanent, then the risk is justified.

Intended Courses and Levels

Engineering classes that could benefit from engaging in this case study might include:

- Thermodynamics I and II
- Thermal Systems courses such as Power Plants
- Engineering Management

Business classes that could benefit from engaging in this case study might include:

- Business Policy
- Project Management

Conducting Case Study in Classroom

This case study has the potential to enhance teamwork and individual work of the students.

Teamwork:

This case study is expected to be used by student groups that are taking one of the above courses. The students would be divided into four groups and each group would be provided a specific assignment.

Group A: Assume the role of Patrick. This position chooses to revert to the previous configuration of the tower result ing in an efficiency of 91%. The students will learn the pros and cons of the alternatives to defend their decision.

Group B: Assume the role of Kerry. This position chooses to modify the tower based on John Cooper's latest recommendation. The students will learn the pros and cons of the alternatives to defend their decision.

Group C: Assume the role of Robert Moye and the Southern Company management. Given the arguments presented by both sides, choose the best alternative.

Group D: Assume that you have the opportunity to speak with John Cooper. What questions would you have for him? What information would you like to know more about? Also, elaborate on some methods to eliminate risk by gathering more information about the cooling tower system.

Individual Work:

The students will answer the Interact questions on the CD-ROM thereby learning about how to apply the theories in engineering and business to a real-world problem.

Connection to Theories in Engineering and Business

A. Engineering theories:

1. Thermodynamics:

Thermodynamic processes are involved in the exchange of heat between the two fluids through basic heat transfer and evaporative processes. The importance of cooling towers comes primarily from the large amounts of heat that can be removed during evaporative processes. (Cengel, Chapter 13)

2. Heat Transfer:

   Great efforts are made to distribute the water in the cooling tower to maximize performance. The maximum performance comes from the greatest heat transfer attainable. To maximize heat transfer, the water is splattered off splashplates to increase the surface area exposed to air of the hot water. Also, to maximize heat transfer, water distribution is configured to even out the cooling load across the area of the tower. This does not mean that equal amounts of water are sprayed everywhere necessarily, but that the exiting temperature is uniform across the tower. In addition, cold air is not rushing through the tower anywhere and hurting the tower's efficiency. (Beiser, Section 14-4, 14-7)

3. Fluid Dynamics:

   In complicated grids of piping, there is difficulty in describing the entire fluid flow system and its behavior without the aid of computers. Even then, there is discrepancy between computational results and actual results. The importance of proper water distribution in the cooling tower makes an understanding of fluid dynamics important. In the case of Plant Vogtle, the high riser water levels and related turbulence are blamed for hurting the distribution pattern.

4. Power Plant Engineering:

   There is a direct relationship between the circulating water temperature and the backpressure on the turbine. This backpressure inhibits rotation of the turbine so reduction of this pressure will make the turbine more efficient. If the circulating water temperature can be reduced a few degrees, it can give the power plant 5-7 MW increase. This demonstrates the importance of having a cooling tower operate at its highest potential. (Li, Chapters 6, 8,9)

B. Business Theories:

1. Risk Assessment and Management:

   In choosing between alternatives for a project, risk of the alternatives must be evaluated. Some risk aspects can be firmly evaluated, such as cost impacts, while others may be more subjective, such as credibility. Taking the risk assessment into account, choices can be made more comfortably because the consequences are more readily understood.

2. Project Evaluation and Selection:

   Choosing between alternatives often involves many considerations including risk, cost, and financial gain. These factors must be weighed based on importance and reliability of the factors to choose the best alternative. Often there may be more than one acceptable alternative, so how the factors are ranked plays a decisive role in project selection.

Basis of Research

With permission of the Southern Company, this case study was constructed around a dilemma that the company faced in 1999. Interviews were conducted with a number of engineers at the Southern Company's Plant Vogtle and with John Cooper, the tower consultant. Site visits were also made during shutdown so that a deliberate effort could be made to gather information that is not readily available during operation. This includes the photographs inside and beneath the tower. Internal documents related to this problem were also gathered with the permission of the Southern Company and, where relevant, have been included in the case study.

In an effort to more thoroughly present the basic theories of cooling towers, various texts were consulted. These are:

Baker, Donald. Cooling Tower Performance. Chemical Publishing Co., New York, NY, 1984.

Beiser, Arthur. Physics. 5th Ed., Addison-Wesley Publishing Company, Reading, Massachusetts, 1991.

Cengel, Yunus A. and Michael A. Boles. Thermodynamics: An Engineering Approach. 2nd Ed., McGraw-Hill, Inc., New York, 1994.

Li, Kam W. and A. Paul Priddy. Power Plant System Design. John Wiley & Sons, New York, 1985.

Willenbrock, Jack H. and H. Randolph Thomas. Planning, Engineering, and Construction of Electric Power Generation Facilities. John Wiley & Sons, New York, 1980.

Defense of Alternatives

Alternative A: Revert to Previous Configuration

Students are expected to cite past modifications' lack of expected success and the low risk of this alternative as the primary reasons for choosing this alternative. An efficiency of 91% compared to 79% should mean nearly around $1.5 million in realized income to Plant Vogtle over the plant's remaining life. John Cooper has presented his modifications twice, each time with decreased performance, and this strongly brings his credibility into question. The students will ask why should they and how can they trust John Cooper again. What evidence has he shown to prove that there is turbulence at the riser-flume interface? During the interview, John simply states that this is the problem, without data to confirm it. He also considers tower modification to be somewhat of an art.

Furthermore, John Cooper has seemingly changed his position on tower water distribution. He originally supported zones of differing flowrates, created by different nozzle sizes, but has suggested a new modification with a single flowrate. With the previous modification's decreases, some change in philosophy may be expected, however. Also, John Cooper notes that a previous modification of his (implemented at Watts Bar) had performed above design specifications with a single nozzle size. This contrasts with John's explanation of how air entering the tower is preheated by the time it reaches the center, requiring less water in the tower's center. This indicates a need for smaller nozzles in the center of the tower.

The certainty of this modification is attractive when compared to the alternative. There is no guarantee that the new modification will result in an efficiency above 91%, or even above the present condition of 79%. If the tower does not exceed 91%, then the tower will have to be modified again to this configuration at the next shutdown anyway. If the previous modifications are included in the costs of implementation (assuming comparable numbers for earlier mods), to get the tower back to 91%, it will have cost $300,000. If the new modification is implemented and does not succeed as planned, it will drive the cost up further because of the necessary future change. There is a tradeoff point where the cost of modification exceeds the cost benefit of the modification.

Alternative B: Implement the New Modification

The primary attractiveness of this alternative is the long term cost benefit. Millions of dollars gained at the expense of hundreds of thousands seems to be a no-brainer. The drawback is the uncertainty involved with this alternative. Not only is there uncertainty concerning the outcome of the modification, specifically, how close to 100% efficiency is the tower going to be, there is also uncertainty with John Cooper himself. Before this modification is implemented, some thought should be given to the credibility of John Cooper. He has a track record of success everywhere but Vogtle. This is Vogtle though. Quantifying this risk is difficult and the way to fight around this credibility issue is to understand what is occurring in the tower.

John Cooper offers an explanation for the distribution problems in the tower. The turbulence at the riser-flume interface intuitively seems like a viable cause for problems in water distribution. This intuition is without verification, however, so some decision has to be made about the likelihood that this is the problem.

Concerning the single nozzle configuration, a single nozzle size seems logical. According to the temperature mappings, the interior of the tower is cool, so more water is needed. In the perimeter of the tower the temperature is warmer, so less water is needed. The modification to a single nozzle size accomplishes this goal since the current configuration has smaller nozzles in the center and larger nozzles at the perimeter (compared to the suggested new nozzle size of 1.25"). The question is with the actual size of the nozzle, not the layout of the tower.

Also, considering the reasoning in this modification, it is worth the risk knowing that if it is not successful, a modification to the other alternative can be made later. This is the 'one more try, we'll get it this time' outlook. Risking another $100,000 is acceptable in this case because of the potential for a $3 million gain.

Further Discussion:

There are more avenues available for pursuit in this case study such as quantifying risk and testing. This is a good opportunity for students to brainstorm for ideas that may help determine which alternative to choose. Students are not expected to be entirely comfortable choosing one method over another, closely approximating real-life decisions they may need to make later in their professional lives. This discomfort will indicate to students that more information is needed and this is the chance to ask students what information would have made the decision easier.

In situations with limited information or insight, risk assessment becomes more subjective. The students should question their assessment of the risk involved in this change.

Also, students are likely to see that more knowledge is necessary to eliminate the uncertainty with this modification. There may be suggestions for more operational tests in the tower before any modification is carried out, including measuring the water flowrates in different regions or attempting to determine the effects of turbulence at the riser-flume interface. Determining some of these parameters may aid in more accurately modelling the tower with software. Furthermore, students may question the source code used for John Cooper's computer model and seek this information for evaluation. Among all of the potential testing options, students may even suggest building a model of the tower for a greater understanding of the tower operation.

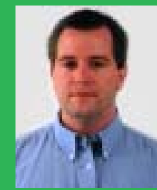
Epilogue

A. What did the Southern Company do?
The Southern Company chose to modify the tower based on John Cooper's latest recommendation. This change was implemented during the reactor 2 shutdown in October 1999.

B. Why did the Southern Company choose that option?
The Southern Company performed an analysis of the financial benefit of the new modification based on potential gains. The relatively small cost of implementing the change versus the payoff if successful made the decision for the company. Based on the best available information, the company believed that the latest modification should work.

C. What was the result of this choice?
Preliminary data from temperature measurement points around the facility during the winter indicated that the modification did not have the expected results. During the following summer, performance tests were performed and, indeed the modification had not resulted in the performance of 100%. In fact, the tower was performing at approximately 85%, lower than the previous configuration of 91%.

D. What does the Southern Company believe at this point?
Further investigation into the differences in the towers at Vogtle and the other towers manufactured by the same vendor discovered that the flumes in the Vogtle towers protrude into the risers. Consideration is being paid to the removal of the protrusions that may be causing turbulence at the riser-flume interface.



Justin Cochran is currently a PhD Candidate in Management Information Systems at the University of Georgia. He previously graduated from Auburn University with M.S. and B.S. degrees in Mechanical Engineering. During his time at Auburn, he was a cooperative engineer in the manufacturing engineering department at a fitness equipment manufacturer. Additionally, he spent four years working with the Laboratory for Innovative Technology and Engineering Education. Justin was also the recipient of the Birdsong Study Abroad Fellowship from the College of Engineering at Auburn University, which enabled him to study photography in Australia. His current research interests are technology strategy and enterprise systems.

P.K. Raju **is Thomas Walter Professor of Technology Management & Director of Auburn Engineering Technical Assistance Program in the Mechanical Engineering Department at Auburn University. Dr. Raju has directed and managed a variety of sponsored research and development projects. These projects have dealt with different aspects of acoustics, vibration, noise control, non-destructive evaluation, and engineering education. These projects have been funded by industries (John Deere, Louisiana Pacific Corporation, Wheelabrator, American Gas Association) and government and international agencies (UNDP, NASA, NSF, DOD, DOE, NIST) and totals over $4.1 million. Dr. Raju has authored or edited 18 books, published five book chapters and has published a total of 129 papers in journals and conference proceedings. He also is the co-author of eight books on engineering management published by Taveneer Publishers in 2000 and 2001. Dr. Raju is a member of the ASME, ASEE, INCE, ASA, ASNT, INCE. He served on the executive committee (1992-1996), and as Chairman of the ASME Noise Control and Acoustics Division (1996-1997), and served as Assistant Vice President Region XI (1994-1995). He also served as president of the Alpha Upsilon Chapter of Phi Beta Delta, Honor Society for International Scholars (1996-1997). He could be contacted at pkraju@eng.auburn.edu.**

Chetan S. Sankar **is the Thomas Walter Professor of Management at Auburn University's College of Business. He received his Ph.D. from the Wharton School, University of Pennsylvania and has worked at Temple University and at AT&T Bell Laboratories. He is a Co-Principal Investigator of four National Science Foundation grants worth more than a million dollars. The objective of these grants is to develop exceptional instructional materials that bring real-world issues into classrooms and to improve the higher-level cognitive skills of students. These instructional materials have been published and made available as nine textbooks that include multimedia CD-ROM supplements. In addition to his current research and teaching interests, Dr. Sankar has published more than 100 papers in journals, book chapters, and conference proceedings. He has won many awards for research and teaching from the Society for Information Management, NEEDS and John Wiley and Sons, Decision Sciences Institute, American Society for Engineering Education - Southeastern Section, American Society for Mechanical Engineering, Auburn University, and the Project Management Institute. Further information about Dr. Sankar's research and teaching accomplishments could be obtained from the web site: www.auburn.edu/~sankacs.**