Texas Industries of the Future

Evaluation of Water Curtailment on Energy Use and Plant Net Profitability

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Prepared by

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Acknowledgements

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Disclaimer

While this analysis incorporates specific process cooling technologies, no endorsement of any technology or product is intended or made.

Executive Summary

In 2011 Texas experienced a record drought. This drought served as a wake-up call to Texas municipalities and industries. Depending upon their location, Texas process industries were faced with the serious possibility of curtailments of water supply. Although today much of Texas does not face the severity of the 2011 drought, the challenge of how to prepare adequately for such an event continues to be a question.

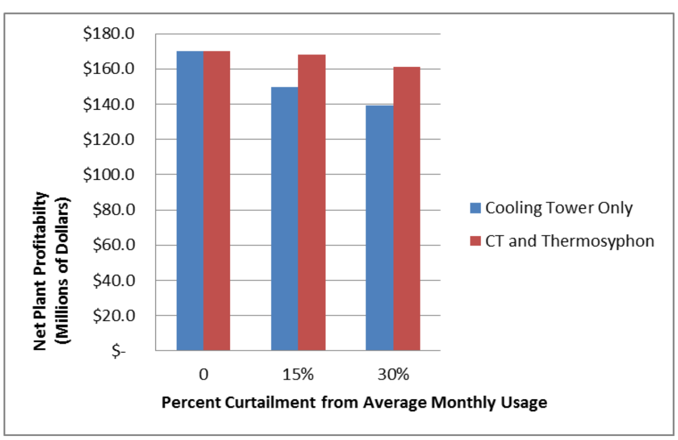
In response, the "*Technology Forum: Sustaining Industrial Energy Efficiency in Process Cooling in a Potentially Water-Short Future*" , was convened on June 19, 2013 in Houston, Texas to bring together end-users in chemical plants and refineries with the developers of technologies that provide process cooling. Attendees identified the need to be able to **compare the performance of wet, hybrid and dry cooling technologies based on capital and operating costs, water, and energy impacts.** This report presents a methodology for making this comparison.

This report is not intended to be comprehensive in terms of inclusion of technologies, nor detailed in terms of impact evaluation. Rather, the purpose is to define a baseline for a Reference Plant, develop several possible curtailment scenarios, and present the costs and benefits of a range of responses to a curtailment, including the no-action scenario. This type of information is needed by decision-makers contemplating responses to drought scenarios.

Under the Business As Usual (BAU) scenario, the Reference Plant, a chemical plant in the Houston region using only a cooling tower for process cooling, shows a plant net profitability (PNP) of $170 million based on production of 500 million units. Water is not a constraint under this scenario. This defines the baseline for PNP, water use and energy use.

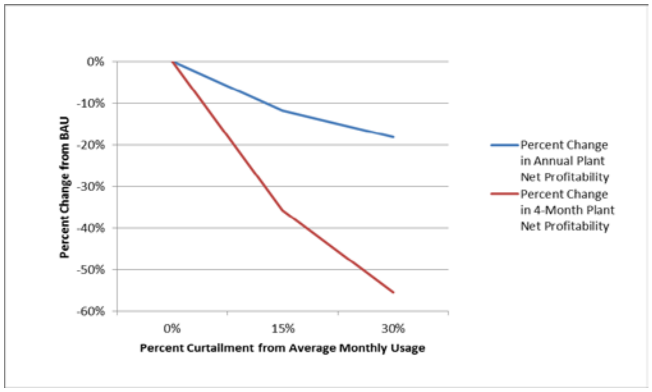
The blue bars (a cooling tower only scenario) in Figure 1 illustrate the impacts of a 4-month water curtailment of 15% and 30%, calculated from a 12-month average. For the 30% curtailment over 4 months scenario, PNP is reduced to $139 million, a drop of 18% from BAU on an annual basis. This compares to a drop in PNP of 5% for the same plant running a cooling tower and a hybrid cooling technology, the Thermosyphon, under a 30% curtailment scenario.

Figure 1: Impacts of a Four-Month Water Curtailment
On Annual Plant Net Profitability



However, any drop in PNP is experienced over the period of reduced production, not throughout the year. Viewed from this perspective, the reduction of $31 million for the scenario with the cooling tower only would be a 55% drop in PNP for the four-month period, compared to the BAU (no water curtailment). The 30% curtailment over four months is the worst-case scenario that was modeled. Figure 2 compares the reductions on a percentage basis for the 15% and 30% curtailment scenarios, on both an annual and 4-month basis.

Figure 2: Percent Change in Plant Net Profitability as a Function of Curtailment Severity: Annual Vs 4-Month Period PNP (Curtailment June-September)



The energy intensity of the product increases under any curtailment level for the Cooling Tower Only scenario. However, using both the cooling tower and the hybrid technology resulted in an improvement in energy intensity from the BAU case.

Conclusions

This analysis of water curtailment on Plant Net Profitability (PNP) and energy use highlights the following points:

- In order to understand how water curtailment impacts a process plant's operations, it is necessary to model plant operations, including water, energy, and financial inputs, for each process cooling technology under consideration.
- As expected, a water curtailment of 15 to 30 % for four months has a significant impact on PNP. For the 30% curtailment for 4 months scenario, the worst case scenario, PNP is reduced to $139 million from $170 million, a drop of 18% on an annual basis. However, the drop in plant profitability is not linear as one goes from 0 to 30 % water curtailment.
- The drop in PNP would be experienced over the period of the curtailment, in this case June-September, not throughout the year. Viewed on this basis, the reduction of $31 million would be a 55% drop in PNP for the four-month period, compared to the PNP over the same four months without a curtailment.
- The addition of the hybrid technology maintained production levels very close to the BAU scenario, resulting in a negligible reduction in PNP for the 15% curtailment scenario. At 30% curtailment levels, PNP decreased by 5%.

- Energy intensity cannot be assumed to increase from the BAU case when other process cooling technologies are added. These results point to the need to fully understand the interaction between water use, energy use and plant costs for the specific technology under consideration.

Background

In 2011 Texas experienced a record drought. This drought served as a wake-up call to Texas municipalities and industries. Depending upon their location, Texas process industries were faced with the serious possibility of curtailments of water supply. Although today much of Texas does not face the severity of the 2011 drought, the challenge of how to prepare adequately for such an event continues to be a question. This is especially compelling given population growth in Texas, projected water demand, and the expansion of chemical manufacturing facilities in response to the availability of inexpensive natural gas. The Texas Water Development Board projects a gap between projected demand and existing supply in 2060 of 6.7 million acre-feet[1]. This shortfall will be met by increased water reuse and development of non-traditional water sources, such as brine aquifers or sea water.

Texas is not alone in facing this challenge. Many regions of the US and world experience water supply constraints, both in terms of quantity and/or quality. To compound this issue, current solutions to address this constraint at chemical plants and refineries can incur an energy penalty. Industry members on the Texas Industries of the Future Chemical Manufacturing and Refining Advisory Committee identified this energy/water tradeoff as an important issue facing them as energy managers charged with energy intensity improvements.

The "*Technology Forum: Sustaining Industrial Energy Efficiency in Process Cooling in a Potentially Water-Short Future*" , was convened on June 19, 2013 in Houston, Texas to bring together end-users in chemical plants and refineries with the developers of technologies that provide process cooling. The focus of the Forum was on process cooling applications that use less water. The day-long meeting was organized by the Texas Industries of the Future at the University of Texas at Austin, with the support of the Institute of Industrial Productivity. Thirty-seven attendees from 11 chemical manufacturing and refining companies, 7 technology developers, and 6 interested organizations gathered to discuss the need for process cooling technologies that use less water. A final report and presentations from that meeting can be found at http://texasiof.ceer.utexas.edu/docs_pres/conferences.htm

A common concern across the board was that "water is cheap until it's gone", which makes it challenging to engage management and secure capital for technology investment before there is a crisis. One of the challenges is that there is no "apples to apples" comparison of what is at stake when curtailment occurs. Attendees identified the need to be able to **compare the performance of wet, hybrid and dry cooling technologies based on capital and operating costs, water, and energy impacts.** This report presents a methodology for making this comparison.

This report is not intended to be comprehensive in terms of technologies, nor detailed in terms of impact evaluation. Rather, the purpose is to define a baseline for a Reference Plant, develop several possible curtailment scenarios, and present the costs of a range of responses to a curtailment, including the no-action alternative. This analysis begins to illuminate what is potentially at stake.

Goals of the project include:

- Model the impact on profitability, water and energy use for a reference process plant under water curtailment scenarios.

[1] 2012 Texas State Water Plan, Texas Water Development Board.

- Increase end-user awareness of process cooling technologies and options.
- Raise awareness and frame decision-making in terms of risk and potential costs.
- Test the approach for potential use as a web-based tool which would allow the user to customize plant operating data and make their own site-specific comparisons.

Methodology

In order to model the impacts of water curtailment on plant operations, a Reference Plant was defined, with inputs for production, water and energy use, costs, and plant profitability. The Reference Plant, partially described in Table 1, is a chemical plant along the Texas Gulf Coast. Hourly Typical Meteorological Year (TMY) weather data used in the modeling was from Hobby Airport[2].

Table 1: Reference Plant Characteristics

Design Plant Capacity, Units/Year	500,000,000
Design Production Rate, Units/Hr	57,078
Maximum Production Rate, Units/Hr	60,000
Design Cooling Tower CWT, °F at Design Production Rate	89
Waste Heat Generated Per Unit, BTU	1,270.20
Minimum Process CWT, °F at Max Production Rate	67
Maximum Process HWT, °F	120
Change in Waste Heat / °F Change From Design CWT	1.00%
Water Allocation (GPM)	200
Circulating Flow (GPM)	5,000

The Water/Energy Committee of Texas IOF developed the following scenarios on water curtailment. The scenarios represent curtailment scenarios which might be possible, given the conditions of 2011. The scenarios vary two factors:

- Length of curtailment. Curtailment is varied from 1 to 4 months. A one month curtailment occurs in August. A four month curtailment runs from June through September.
- Severity of curtailment. Curtailment is varied from 15% to 30% of the baseline monthly average, calculated based on average monthly usage in the previous 12 month period.

The following technologies were included in the modeling:

- An open cooling tower.
- The Thermosyphon Cooler Hybrid System (TCHS), a combination of equipment and controls, employs a sensible heat rejection device, a thermosyphon cooler (TSC), in conjunction with an evaporative heat rejection device, an open cooling tower, to satisfy the annual cooling requirements of the Reference Plant. The technology was developed by Johnson Controls. See Appendix 1 for a description of the technology and how it has been included in the model.

Additional hybrid and dry technology developers were approached but were unable to participate due to timing.

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[2] http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/; downloaded in 2014.

The Reference Plant was modeled for the following operations and conditions:

- Open cooling tower, no water constraints. This is the Business As Usual (BAU) case and sets the baseline for water and energy usage, production, and Plant Net Profitability PNP).
- Open cooling tower, water constrained. These scenarios quantify the impacts that might be experienced by a plant facing a 15 to 30% curtailment for 1 to 4 months.
- Open cooling tower and hybrid technology, water constrained. This scenario incorporates an open cooling tower and the TCHS, running in series. Scenarios were run for the Reference Plant facing a 15 or 30% curtailment for 1 to 4 months.

Water curtailment would be expected to impact plant profitability, production, and energy performance, but this impact has not been previously quantified. Central to this analysis is the impact of water curtailment on Plant Net Profitability (PNP). PNP is defined as revenue minus expenses.

Revenue equals the number of units produced multiplied by the sale price per unit of product.
Expenses include all raw material and energy expenses per unit multiplied by the number of units produced, in addition to labor and plant capital costs. This includes costs for the cooling tower fan and pump energy, as well as the chemicals for water treatment, and the cost for the make-up water and any blowdown charges. For the hybrid technology scenario, expenses also include the annualized equipment cost, as well as operational costs associated with the technology (pump and fan electricity). For any scenario which resulted in a reduction in production, a penalty of 10% of cost to manufacture these units was included.

In order to highlight the impacts of water curtailment alone, the prices of water and power are held constant in all scenarios. It is assumed that electricity costs $ .05/kWh. The fully burdened water cost (make-up + chemical treatment + blowdown) used in this analysis was $4.00/1000 gallons of make-up volume.

Results

Under the BAU scenario, the Reference Plant shows a net plant profitability of $170 million based on production of 500 million units. Water is not a constraint under this scenario. This defines the baseline for PNP, water use and energy use.

For the purposes of this summary, results are presented for the 15% and 30% curtailment from June-September. The 30% curtailment for four months is the worst-case scenario for this analysis. Impacts from curtailments of one month are smaller than those depicted here.

Figure 1 illustrates the impacts of a 4-month curtailment of 15% and 30% of average monthly water usage. For the 30% curtailment for 4 months scenario, PNP is reduced to $139 million, a drop of 18% from BAU on an annual basis. However, this drop in PNP would be experienced over a 4-month period, not throughout the year. Viewed on this basis, the reduction of $31 million would be a 55% drop in PNP for the four-month period, compared to the PNP over the same four months without a curtailment.

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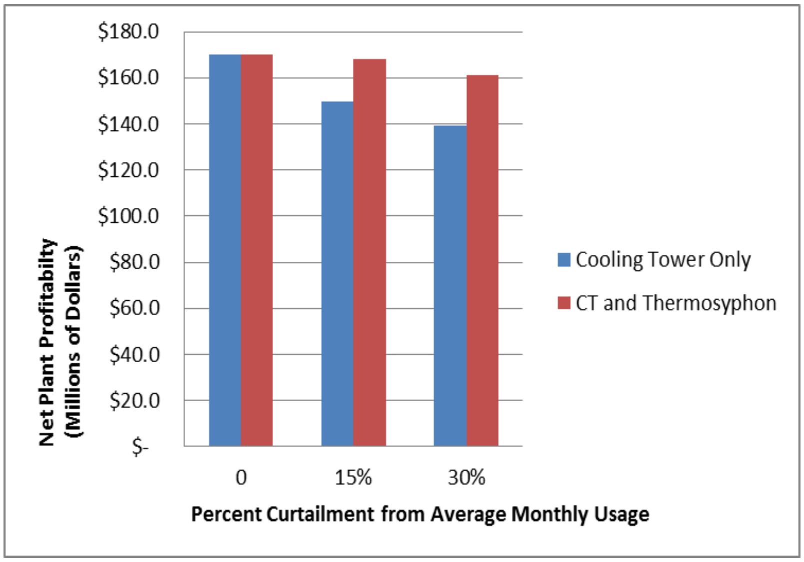

Figure 2 compares the reductions on a percentage basis for the 15% and 30% curtailment scenarios, on both an annual and 4-month basis.

Figure 2: Percent Change in Plant Net Profitability:
Annual Vs 4-Month Period PNP
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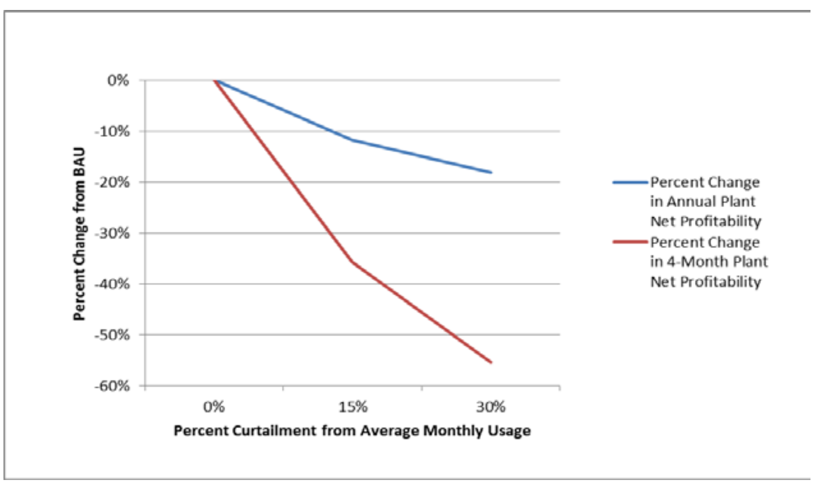

As shown in Table 1, the energy intensity of the product increases under any Curtailment Scenario for the Cooling Tower Only scenarios. However, using both the cooling tower and the hybrid technology resulted in an improvement in energy intensity from the BAU case. These results point to the need to fully understand the interaction between water use, energy use and plant costs for the specific technology under consideration.

Table 1: Impact of 4-Month Curtailment on PNP and Energy Intensity From Heat Rejection System

Technology	Water Curtailment Scenario	Units Produced (Millions)	Plant Net Profitability (Millions)	Electricity Consumed by Heat Rejection System (kWh)	Energy Intensity From Heat Rejection System (kWh/unit)	Percent Change in Energy Intensity from BAU[3]
Cooling Tower Only	0% (BAU)	500	170	2,308,400	0.0046	0%
	15%	456	150	2,195,400	0.0048	4%
	30%	433	139	2,118,900	0.0049	6%
Cooling Tower and TSC	0%	500	170	1,964,000	0.0039	(15%)
	15%	499	170	2,188,000	0.0044	(5%)
	30%	481	161	2,163,100	0.0045	(3%)

Conclusions

This analysis of water curtailment on Plant Net Profitability (PNP) and energy use highlights the following points:

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- Energy intensity cannot be assumed to increase from the BAU case when other process cooling technologies are added. These results point to the need to fully understand the interaction between

[3] A number in ( ) indicates a decrease in energy intensity from the Business as Usual (BAU) case, which would be considered an improvement in energy performance.

water use, energy use and plant costs for the specific technology under consideration.

Appendix 1: Description of Process Cooling Technology Included in the Model

Description of Process Cooling Technology Included in the Model

Name of Technology	Thermosyphon Cooler Hybrid System
Size	Half Module Size for the plant modeled
Capital Cost	Approximately $1,000,000 installed
Company	Johnson Controls
Contact Name	Tom Carter
Contact Telephone	717-816-7261
Contact Email	thomas.p.carter@jci.com
Short Description (250 words)	The Thermosyphon Cooler Hybrid System (TCHS), a combination of equipment and controls, employs a sensible heat rejection device, a thermosyphon cooler (TSC) in conjunction with an evaporative heat rejection device, an open cooling tower, to satisfy the annual cooling requirements of a given process application. By reducing the evaporative heat load on the cooling tower, the TCHS can significantly reduce the annual water consumed for cooling while still maintaining the plant's peak process output on the hottest summer days. Control logic incorporated into the TCHS balances the cost of electrical power with the cost of water to provide the lowest system operating cost. The TSC, which incorporates a naturally recirculating thermosyphon refrigerant loop, is specifically designed to operate within the efficient open cooling tower water circuit where special attention needs to be paid to assure ease of cleanability, low pressure drop, system control, and freeze protection.
Footprint of Unit	Approximately 58' x 29'
Estimated Time from Order to Operation	9 to 12 months

The concept pictured below shows a full TSC module