SHORT NON-REFEREED PAPER (PREVIOUSLY PUBLISHED)

THERMAL UPGRADING OF INJECTION WATER COOLING TOWERS

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Introduction

Sugarcane factories use a large quantity of water. The water content in sugarcane is typically about 0.70 m^3/ton of cane crushed, and theoretically this is sufficient for sugarcane processing, with the surplus water exiting the plant in an effluent stream (Rein, 2007).

A recirculation cooling system uses the same water repeatedly for process cooling. The heat that is absorbed by the water needs to be dissipated in order for the water to be reused for the intended cooling application. Spray ponds and cooling towers are the most common form of heat sink used to re-cool the recirculating water for this purpose. The cold or rather re-cooled water temperature exiting a cooling tower or spray pond and returning to the process is often a limiting factor in process plants. In sugar factories in particular, this has a direct impact on the vacuum in the evaporators and pans, thereby affecting the quality of sugar produced, steam consumption and overall plant efficiency.

A sugar factory's cooling water temperature is influenced by a number of factors, many of which occur over an extended period of time and result in a gradual deterioration in the cooling tower's thermal performance. The impact of this isn't immediately noticed but over time, efficiencies can be significantly reduced. This paper looks at various aspects that affect cooling tower performance and gives suggestions on how to reduce and maintain temperatures to design specifications.

Cooling Tower Performance

Design parameters

Cooling tower design parameters are typically determined before the cooling tower is purchased. These parameters are as follows:

- Plant capacity and cooling tower flow rates
- Cooling duty based on cooling tower inlet and desired outlet temperatures
- Ambient wet bulb temperature
- Approach to wet bulb temperature
- Site altitude
- Heat rejection rate.

Environmental factors

Wet bulb temperature and approach

In a well-designed cooling tower, air and water are intimately mixed and the re-cooled water temperature can be reduced to a value approaching the entering air wet bulb temperature. The difference in these two temperatures is referred to as the approach to wet bulb or simply the 'approach' (Morgan, 1977). The more efficient a cooling tower design, the tighter or closer the approach to wet bulb will be and visa verse. Typically, a design approach will be in the range of 6-8°C (Morgan, 1977). The relationship between re-cooled water temperature and wet bulb is not linear in nature, i.e. the approach is not constant and for the same thermal duty increases at lower wet bulb temperatures.

Assuming constant fan speeds (mechanical draught cooling towers), the re-cooled water temperatures from a cooling tower vary with the ambient wet bulb temperature. Figure 1 shows the relationship between re-cooled water temperature and wet bulb temperature for a typical industrial mechanical draught cooling tower (assuming constant flow rate, heat rejection and fan speed). The cooling tower performance is calculated using the methodology published by Kröger (2004).

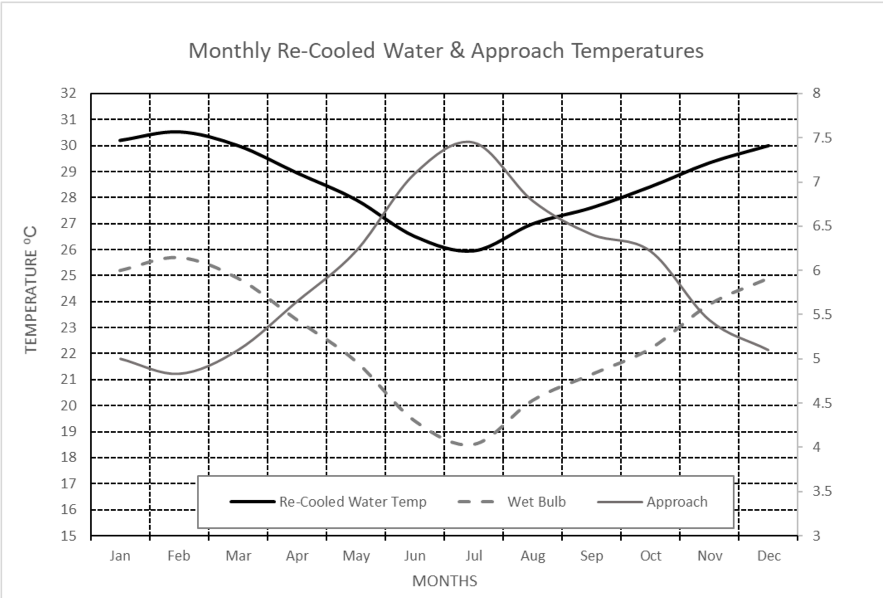

Figure 1. Monthly re-cooled water temperature – Umhlanga (2017).

Wet bulb temperatures vary significantly for different geographic areas; typically cooling tower design wet bulbs for industrial cooling tower users are specified as the hottest month in the 0.4% percentile, (ASHRAE, 2017). As can be seen in Figure 1, the period in which the maximum wet bulb temperature is experienced is very short and some cooling tower vendors or engineering contractors may therefore specify a lower wet bulb for the cooling tower design as this significantly impacts cooling towers sizing and therefore the capital cost of the cooling tower.

Water quality

The quality of the make-up water supply to a cooling tower combined with environmental factors such as airborne particulate levels can significantly impact cooling tower performance over time. Inadequate or poorly managed water treatment programs coupled with poor fill selections can result in a rapid deterioration in cooling tower performance. Cooling tower thermal performance using traditional high efficiency film packs in 'dirty' applications suffer far greater thermal performance degradation than cooling towers equipped with low fouling film, trickle or splash pack fills.

High efficiency film packs equate to smaller footprint, lower capital cost cooling towers and are consequently a popular choice when specifying a cooling tower for a particular project. This equipment can prove costlier from a life cycle perspective due to the requirement for frequent repacking of the cooling tower as well as the consequential performance losses experienced by the process/production plant as a whole.

Other factors

It is common place that additional cooling load due to increased production capacity is added to the cooling tower. This is normally only apparent in peak summer periods when maximum production is required at peak wet bulb temperatures, i.e. the present cooling tower duty is greater than the requirements for which the cooling tower was purchased.

Furthermore, some cooling towers may have been intentionally initially under-sized due to the supplier/contractor assuming a level of thermal risk to ensure competitive pricing.

Improving cooling tower thermal performance

Cooling towers are comprised of a number of components, some of which provide a greater opportunity for upgrading than others. These are as follows:

- Fan and motor assembly (mechanical draught cooling towers)
- Water distribution system
- Fill or packing.

Fan and motor assembly

The least expensive and by far the simplest upgrade is to improve air volumes through a cooling tower. This is simply achieved by increasing blade angles to the maximum blade angle allowed by the installed motor power.

The installation of a velocity recovery stack or discharge evase (an evase can be defined as a passage of gradually increasing area through which the air discharged by a fan must pass and is shown in Figure 2) generates approximately 5-8% (subject to the geometry thereof) more air flow for the same fan shaft power due to pressure regain resulting from the controlled expansion of air and consequent recovery of velocity pressure. In the typical industrial cooling tower referred to under ‘Wet bulb temperature and approach’, the installation of a 4 m high discharge evase equates to a reduction in the re-cooled water temperature of 0.5°C at the design condition.

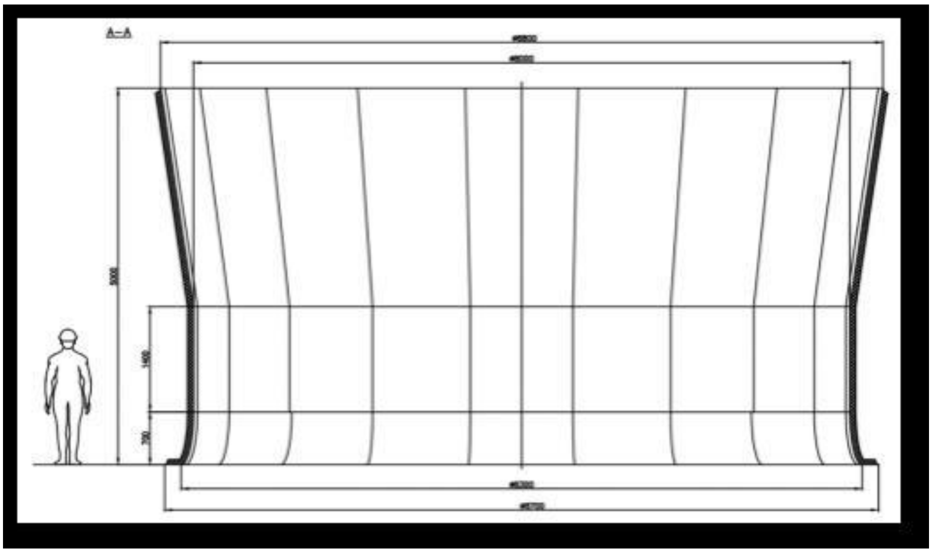

Figure 2. Fan casing with evase (www.wentech.eu, 29 March 2019).

Increase motor installed power

This needs careful consideration as the power ratings of the various components of the drive arrangement as well as the electrical reticulation system need to be evaluated. Additionally, the fan performance characteristics themselves e.g. allowable blade pressures need to be evaluated and may require the installation of additional blades or a different impellor entirely.

Water distribution system

Poor water distribution is one of the primary causes of poor cooling tower performance and while improving the water distribution isn't necessarily a thermal upgrade it is critical in ensuring that cooling tower performance is maintained. That said, existing distribution systems can be greatly improved by installing modern, full cone (Figure 3), square spray pattern nozzles (Figure 4) or modern gravity sprayers.

Figure 3. Full Cone Sprayer Nozzles (Industrial Water Cooling Pty Ltd).

Figure 4. 'Clean' water application up sprayer fitted to 'dirty' water cooling tower.

Fill or packing

Perhaps the most substantial improvement in cooing tower performance can be achieved by replacing existing fill that is either clogged or damaged with a highly efficient film or trickle pack type of fill.

Subject to the condition of the existing fill, a significantly closer approach to wet bulb temperature can be obtained with change to high efficiency film fill. Replacement of splash pack type fills with higher efficiency cellular fills e.g. vertical, non-fouling film packs has a similar impact on cooling tower performance. For example, replacing 3 m of splash grids (200 mm spacing) in a small industrial cooling tower, designed for 6.5 MW of heat rejection, with a vertical fluted film pack, a reduction in the re-cooled water temperature of 1.2°C at design fan shaft power and wet bulb temperature can be expected.

Unfortunately, sugar factory cooling towers have near perfect conditions for the development of biological growths being a warm wet environment, pH in a suitable range and a plentiful supply of nutrients (Chouha and Chandakar, 2014). These conditions narrow down the choice of potential fills to those with more open, structures that offer little scope for blockage due to biological growth. Figure 5 below shown a typical cooling tower splash pack comprising of rigid injection moulded grids, grid supports and stainless steel hanging wires. Splash grids are therefore the most common choice for sugar factory cooling tower applications.

Figure 5. Splash grid fill (Industrial Water Cooling Pty Ltd).

The Myth of Self-Cleaning Fills

A splash grid fill is designed to break the mass of falling water into a large number of drops and in so doing, the water surface area exposed to the air stream increases and as a result the amount of heat transferred to the airstream also increases primarily due to evaporation. As these droplets fall through the cooling tower fill-zone they collide with successive layers of splash bars resulting in a redistribution of water and increased heat transfer due to formation of fresh droplets. The effectiveness of any splash grid design is therefore governed by its ability to form multitudes of droplets of the smallest possible diameter and the airflow resistance of the grids utilised.

In order for a splash grid to effectively generate multitudes of small droplets sufficient kinetic energy (falling droplet) is required before it strikes a rigid bar. The closer the grids are spaced together the lower the kinetic energy of the falling droplet will be (subject to airflow velocities) and the more flexible the splash bar the less effective it will be in utilising that kinetic energy to redistribute the water.

There has been a recent trend, particularly in the sugar industry to make use of plastic mesh type fills, these typically produced from a plastic mesh originally intended for use as geo-stabilising material in earthworks etc. For the reasons outlines above, i.e. these mesh type splash fills are less efficient from a heat transfer perspective than the traditional injection moulded grids developed over many years by the likes of Hamon, GEA, and Industrial Water Cooling (Pty) Ltd.

The plastic mesh fills are purported to be self-cleaning in nature, however, no reference could be established to support this theory. The constant flexing and vibrating of the mesh is the mechanism on which this theory is based. Figures 6 and 7 demonstrate that, within the context of a sugar factory that this claim may be false.

Figure 6. Mesh type fills.

Figure 7. So-called ‘self-cleaning’ fill.

With proper fill selection being the biggest contributor to cooling tower performance it is essential to ensure that any cooling tower upgrade or refurbishment is undertaken with proven fills. There are several cooling towers that have been repacked with ‘home grown’ fill materials for which there is little or no thermal or pressure drop data available. Whilst these fills may provide a low-cost solution, they come with no guarantee that the cooling tower performance will meet the original cooling tower design point let alone provide any increase in thermal performance.

Maintaining cooling tower performance

Water quality

Cooling system efficiencies are highest when the heat transfer surfaces in cooling towers and other heat exchangers equipment, e.g. plate heat exchangers are clean and free from deposits of algae.

Variations in make-up water quality and cooling tower operating environments subject cooling towers to the following key water treatment issues:

- Corrosion
- Scaling
- Fouling
- Microbiological activity (as shown in Figure 8).

Figure 8. Organic growth on cooling tower drift eliminators.

If not properly controlled, these key issues can negatively impact on the value of the entire process plant or operation. Some examples are as follows:

- Increased maintenance
- Equipment repair or replacement cost
- More frequent shutdowns for cleaning and replacement of system components
- Reduced heat transfer efficiency and therefore reduced efficiency of the process being cooled resulting in a decrease in vacuum available in condensers and evaporator pans.

Mechanical maintenance

Cooling tower fans and distribution systems (particularly sprayers) should be inspected regularly. “In a factory in Swaziland, immediate improvement to the injection cooling water temperature was witnessed when a number of cooling tower fans that had only two blades were reinstated with four-blade fans. Amatikulu mill TPD figures in the 2007/08 season increased for three weeks (33, 34 and 35) during a time when one of the nine cooling tower cells was down due to a defective fan gearbox. Massecuite temperatures and viscosities increased during this period. In factories with spray ponds, regular checks of sprays for blockages should be done during stop days, and wear on spray nozzles should be assessed every off-crop.” (Ninela et al, 2009).

Conclusion

The simple, yet frequently overlooked cooling tower plays a major role in the removal of waste heat from a sugar factory. In many cases a limiting factor of a plant’s production capacity is the quality and quantity of re-cooled water coming from the cooling tower. Many cooling towers constructed over the last 50 years lend themselves to being upgraded and can provide a cost-effective means of increasing plant throughput. Some improvements that can be made are as follows:

- Maximise fan efficiencies with use of discharge evases
- Consider use of variable speed drives on cooling tower fans in order to reduce power consumption in cooler months (Rusch, 2016).
- Implement strict maintenance regime and employ use of condition-based monitoring to predict maintenance interventions and reduce down time.
- Ensure water distribution systems are operated optimally.
- Monitor algae build up on fills and drift eliminators and treat accordingly.
- Before embarking on fill replacement projects do your homework and get as much information as possible.

Energy and water management are very topical considerations in today's climate of ever escalating costs of energy and water. Cooling towers are typically an unexploited source for meaningful reductions in both energy and water consumption.

REFERENCES

ASHRAE (2017). Climatic Design Conditions Handbook. http:/ashrae-meteo.info [accessed 23 June 2019].

Chouha P and Chandakar A (2014). Performance enhancement of sugar mill by alternate cooling system for condenser. International Journal of Technology Enhancements and Emerging Engineering Research, Vol. 2 (Issue 9).

Kröger DG (2004). Air-cooled heat exchangers and cooling towers. Thermalflow performance evaluation and design. Penwell Corp., Tulsa, Oklahoma.

Morgan R (1977). Experiences with Mechanical Draft Cooling Towers in Injection Water Service. *Proc S Afr Sug Technol Ass* 51.

Ninela MB, Muzzell DJ and Love DJ (2009), Maximising process performance in a sugar factory: Issues of design and maintenance. *Proc S Afr Sug Technol Ass* 82: 243-257.

Rein PW (2007). *Cane Sugar Engineering*. Bartens, Germany, 837-839.

Rusch RE (2016). Use of variable speed drives on mechanical draft cooling tower fans. International Symposium on Industrial Chimneys and Cooling Towers, Rotterdam, 2016.

Rusch RE (2017). Thermal upgrading of cooling towers. Proceedings from the 18th IAHR International Conference on Cooling Tower and Air Cooled Heat Exchanger, Lyon, France.