Increasing Water Efficiency in Greenhouse Cooling system in Arid Regions Using Sulfur Burning Technology

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Abstract
Formation of scaling deposits is a serious problem that affects cooling efficiency of the greenhouses in the arid regions, including the UAE. Scaling buildup in the evaporative cooling pads of the greenhouse blocks air flow entry and thus reduces cooling efficiency. Dissolved salts and high alkalinity of the source water are the major cause of scale formation. Most of the scaling inhibition studies and practices are focused on the industrial cooling water processes, however, no studies have been found on the removal of scaling deposits from greenhouse cooling systems. In this study, acidified water was introduced to remove and prevent future buildup of scaling deposits in greenhouse cooling pads. The acid water was maintained by utilizing sulfur by-product from gas production plant using sulfur burning equipment, the average pH of the acid water generated by this technique was 6.5. Eight greenhouses with severe to moderate scaling were selected for this study, where 6 of them treated with acidified makeup water and 2 with normal makeup water in the circulating cooling system of the greenhouse. Water samples were collected daily from each reservoir of the cooling systems, before emptying and after refilling with fresh makeup water, to measure the pH, EC, and the concentrations of cations and anions. The visual observations show that the acidified water was effective in removing the scaling deposits from the cooling pads; as a result the blockages of air flow entry were reduced in all greenhouses treated with the acidified water. The analysis of water samples also confirms that the acidified water was able to dissolve more salts from the cooling pads, as a result, the pH, EC, cations, and anions of the cooling water increased considerably after 24 hrs from adding new makeup water.

Introduction
Scale formation and salt deposits in greenhouse evaporative cooling pads have always been the major threats to the cooling efficiency of the greenhouses in the arid regions including the UAE. During the cooling process of the greenhouse, water evaporates off the pad leaving the dissolved salts and thus, increasing their concentration in the circulating water, this process ends up by precipitating and depositing the salts inside the cooling pad air flow access openings. These deposits reduce the wetting surfaces of the cooling pads, prevent uniform wetting, and reduce airflow through the cooling pads, and hence, reducing the efficiency of cooling process of the air while entering the pads and reducing the amount of cooled air that enters the greenhouses, and therefore, increase in maintenance and replacement costs of the pad.

The potential and speed of scaling and salt deposits increase when the makeup water, which is used for the cooling system in the greenhouses, contains significant amount of dissolved salts, having high pH, and high alkalinity accompanied by bicarbonates. Bicarbonate salts, which are dominant in water of the arid regions including the UAE, usually breakdown to carbonate salts during the cooling process and form scales. Calcium carbonate ($CaCO_3$) is the predominant component of scales deposited from natural water, especially in cooling water systems. The formation of $CaCO_3$ scaling on various surfaces has been extensively studied. Temperature and pH are known to be parameters of particular importance for $CaCO_3$ scale formation. The solubility of the salt decreases with temperature and pH, hence scaling frequently occurs when warm and high pH water is used.

No studies have been found on the scale inhibition and removal from greenhouse cooling pads, however, scaling is a well known problem in the industrial water cooling and heating processes (Shakkthivel *et al.* 2004) and received well attention and considerable investigations. Conventional methods for removing these deposits are expensive and laborious, however, one of the most promising ways to achieve this is to add scale inhibitors into the water (Darton 1997; Hasson *et al.* 1998; Bremere *et al.* 1999; Gill 1999). Many inhibitors have been used in industrial cooling water systems in order to solve these problems (Gehan *et al.* 1991). However, the popularity of inhibitors containing heavy metals is diminishing, because of the concern over their toxic effects (Lake 1988; Levi *et al.* 1988). As a result, the current trend for inhibitor usage is towards more environmentally friendly chemicals.

The objective of this study is to utilize the sulfur by-product from gas production plants in preventing or reducing scaling and salt deposits on the cooling pads by producing acidified water to control the pH of circulating water in the greenhouses. Low pH water tends to consume insoluble carbonates with hydrogen ions turning them into soluble bicarbonates and then into CO_2 and water. Thus, it will prevent the formation of $CaCO_3$ scaling.

Methods

The sulfur by-product from gas production plants, obtained from TAKREER Company, Al-Ruwais, Abu Dhabi, was used in this study to generate acidified water. The sulfur burning unit (Sweetwater Technology®) was installed at the College of Food Systems Farm, the UAE University, Al-Ain, UAE for the purpose of burning the sulfur and producing acid water. The average pH of generated acid water in this unit is 2.5 in the primary discharge line and 6.5 in the auxiliary discharge line. Water from both lines was collected in storage tank and adjusted to pH 6.2 - 6.5 before it is pumped to the distribution tank.

Eight greenhouses were selected to study the effect of acidified water in removing the scale and salt deposits from evaporative cooling pads. The initial conditions of the pads in greenhouses 1 to 6 were that they were older and severely blocked. The pads of greenhouse 7 and 8 were newer and contained less deposit. Acidified water was applied as makeup water to cooling system in greenhouses 1, 2, 3, 4, 7, and 8, while normal makeup water was supplied to greenhouses 5 and 6.

During system operation, water circulates from the reservoir to the top of the pad, then through the pad layers, and finally, collected at the bottom of the pad and send back to the reservoir. To dispose of accumulated salts and to control the system pH, the cooling system reservoir of each greenhouse was daily emptied and refilled with fresh makeup water. Before emptying each reservoir, water samples were daily collected from each reservoir as well as initial acidified and normal makeup water to measure the pH, EC, Ca^{++}, Mg^{++}, Na^{+}, Cl^{-},$CO_3^{=}$, and HCO_3^{-}.

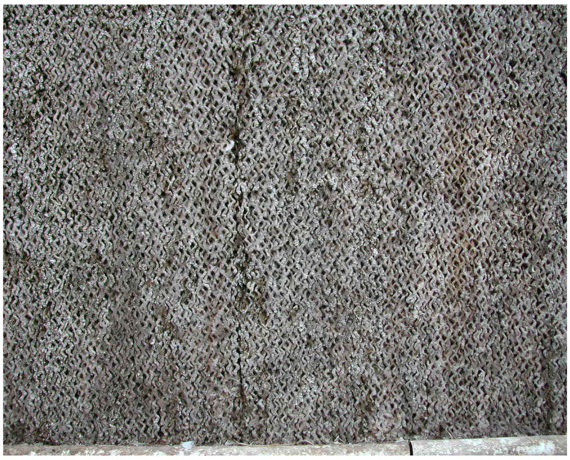
Results

The typical analyses of acidified and normal makeup water are presented in Table 1.

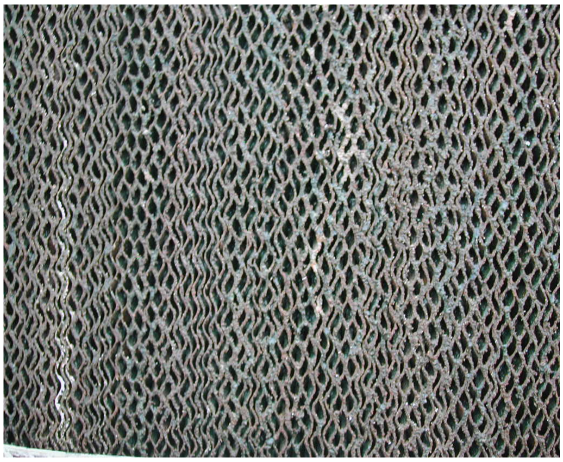
Table 1. The average values of pH, EC, Cations, and Anions in makeup water.

Makeup Water	pH	EC dS/m	Ca^{++} cmol/l	Mg^{++} cmol/l	Na^{+} cmol/l	Cl^{-} cmol/l	$CO_3^{=}$ cmol/l	HCO_3^{-} cmol/l
Acidified	6.46	2.50	2.47	5.36	9.42	19.91	0.00	2.07
Normal	7.88	1.20	0.95	3.61	13.57	10.20	0.00	8.32

The preliminary results of daily changes of pH, EC, carbonate, and bicarbonate in the greenhouse cooling water indicated that the acidified water was effective in removing scale and salt accumulation from the cooling pads. The visual observations in Figures 1 and 2 showed clear evidence that acidified water effectively removed the deposits form the cooling pads.



Before treatment



After treatment

Figure 1. The effect of acidified water in removing scaling and salt deposits from cooling pads.

Initial

After 24 hrs.

Figure 2. The effect of acidified water in removing scales and salt deposits from the cooling pad (dissolved salts in the reservoir of the cooling system).

The pH analysis in Figure 3 showed that there was an increase in the pH of cooling water in all greenhouses from 6.5 to about 9, however, increase in pH with the use of acid water was more significant than that of normal water, as the dissolved carbonates and bicarbonates increased the media pH over time by neutralizing the H^+ ions in the media solution.

The results also showed that the EC of the cooling water was increased from 2.5 to 9 dS/m with acidified water, and from 1.2 dS/m to 4 dS/m with normal water (Figure 4). This is attributed to the fact that acid water removes more accumulated salts of calcium and Magnesium, while the hardness, of normal water, precipitates calcium and other mineral salts, and thus, less changes in EC was observed with normal water.

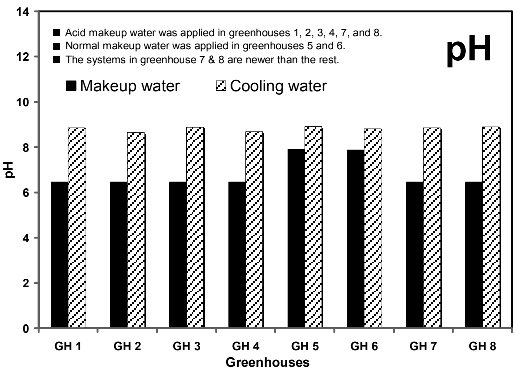


Figure 3. Average pH difference between makeup water and cooling water in the greenhouses after 24 hrs of application

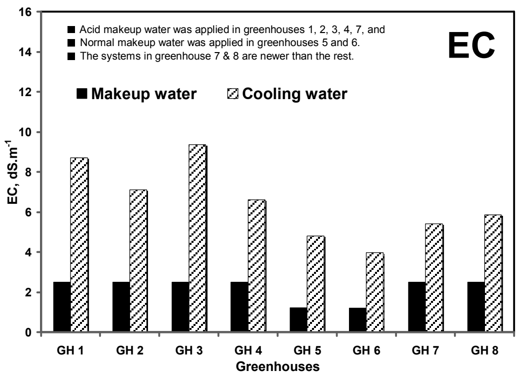


Figure 4. Average EC difference between makeup water and cooling water in the greenhouses after 24 hrs of application

Presence of carbonate was observed in all greenhouses (Figure 5), however, the concentration of carbonate in the cooling water was higher with acidified water. This was attributed to the acids dissolving more $CaCO_3$ and $MgCO_3$. As greenhouses 3 and 4 having more scales and salt deposits, application of acid water will take more time to dissolve the salts, hence, carbonate concentration of cooling water in the greenhouses 3 and 4 was much less.

The average number of changes of bicarbonate in the cooling water is presented in Figure 6. The results show that bicarbonate concentration was increased significantly after 24 hrs. of application in all greenhouses.

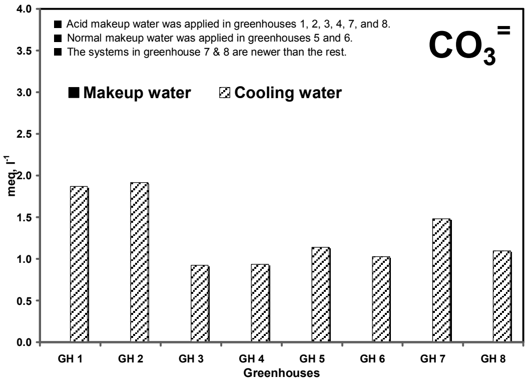


Figure 5. Average $CO_3^{=}$ difference between makeup water and cooling water in the greenhouses after 24 hrs of application

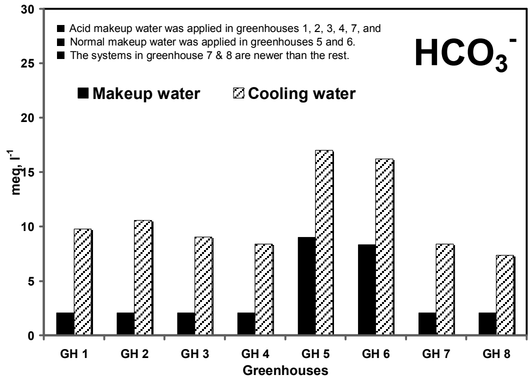


Figure 6. Average HCO_3^{-} difference between makeup water and cooling water in the greenhouses after 24 hrs of application

Conclusion

Application of acidified water in cooling systems of the greenhouses was significantly effective in removing scales and deposited salts from the evaporative cooling pads and prevents future deposits, and hence, improved cooling efficiency of the greenhouses, extending the life of the cooling pads, and reduced the maintenance and replacement costs.

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