

Formation and Cleaning of Mineral Scale on Evaporative Cooling Pads Using a Farm Well-Water Source

by

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Abstract

Well water is used as a primary supply for the evaporative cooling system on many poultry farms. The water quality from wells varies widely. Many producers have issues with the water being over-saturated with minerals that contribute to the scaling of the paper evaporative pads. Study one quantified the rate of mineral scale formation on evaporative cooling pads using one farm well-water source as 168 g per 1000 L of water consumed. Study two quantified scale removal from paper evaporative cooling pads at two scale levels (minimal vs. heavily scaled) using two water sources (well water and municipal). A total of 687 g and 1020 g of mineral scale was removed from the minimally and heavily scaled pads, respectively.

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Chapter 1: Study 1

1.1 INTRODUCTION

There are approximately 25,000 poultry production farms in the United States (National Chicken Council, 2022), representing roughly 100,000 commercial poultry houses. Most commercial poultry houses use recirculating evaporative cooling systems to provide low-cost cooling during moderate and hot temperatures when maximum ventilation alone can no longer provide adequate cooling for the birds. Systems have traditionally been installed with a 15-cm thick engineered fluted cellulose paper evaporative pad (Munters, 2023). These systems utilize the principle of adiabatic cooling, where heat is removed from the incoming airstream by evaporating water from the surface of a wet pad as the air passes. For every gallon of water evaporated, roughly 8,700 BTUs of heat are removed from the air (Campbell et al., 2011).

A common issue for poultry producers is the build-up of mineral scale on evaporative pads. This occurs when excess minerals that are present in the source water are deposited onto the surface of the evaporative pads (Watt and Brown, 1997). Scale build-up can be a particular problem for producers using well water with high concentrations of calcium, iron, fluoride, magnesium, sodium, or other minerals. In a typical evaporative cooling system, the sump is automatically topped off with supply water as water on the evaporative cooling pads evaporates. This is where the system can become supersaturated with minerals if the supply water has high concentrations of minerals. When supersaturation of one of the minerals occurs, precipitation will likely begin to accumulate (Amjad and Demadis, 2015).

Precipitation usually occurs in three steps (Snoeyink and Jenkins, 1980). The first step is nucleation. For precipitation to occur, it needs a particle, usually a fine particle, for the solid

phase to form. This particle that precipitation forms on is referred to as a nucleus. The nucleation process of the precipitate can be either an organized collection of molecules or ion pairs of component ions. This can also include fine particles unrelated chemically to the precipitation, but the particles must possess similarity to the crystal lattice structure. There are two types of nucleation, homogenous and heterogenous. Homogenous nucleation formation involves no influence of foreign particles in the formation of the nuclei. Heterogenous nucleation contains foreign particles in the formation of the nuclei. This nucleation of the precipitate from well water is heterogeneous nucleation because well water contains fine particles of various types of ions. Precipitation solutions must be supersaturated or have concentrations greater than the predicted equilibrium to begin nucleation. Supersaturation energy requirements tend to be less for heterogenous than homogenous nucleation. This is because, in the heterogenous solution, there is more opportunity for precipitation on foreign particles. Although there is more opportunity for nucleation, the foreign surface for the precipitation must be similar in the lattice structure and distance between adjacent ions (Snoeyink and Jenkins, 1980).

The second step in precipitation is crystal growth. The formation of crystals occurs from the accumulation of precipitation ions onto nuclei. Crystal growth rate can be predicted with an equation, but as the properties change in a solution, that rate can vary with time. When a heterogenous solution is open to the atmosphere, like the evaporative cooling systems, the crystal formation can become very hard to predict accurately (Snoeyink and Jenkins, 1980).

The third step in precipitation is agglomeration and ripening of the solids. When precipitation first starts to form as a solid state, it is usually not stable, and can easily return to a liquid solution if the solution becomes undersaturated with calcium. But over time, if the solution stays supersaturated and more calcium scale is allowed to accumulate (ripening stage), the

crystal structure will adjust and become more stable (aging stage). Aging makes it more difficult to return the precipitation that has formed back into solution form. In diverse mixtures of particle sizes, the larger particles will grow first. Often, the larger particles are what is causing the solution to continue to be supersaturated. The concentration in the solution will decrease as large particles grow, causing the smaller particles to dissolve back into the solution to create a more stable solution. Agglomeration increases the transformation of small particles into larger particles. Because of this, the selection of an equilibrium constant for a precipitating solution is challenging. Equilibrium constants reported for individual solids may vary widely because in addition to the effects of the particle size and aging, one must account for factors such as complex formation, absorption of impurities at the crystal interface, and formation of solid mixtures (Snoeyink and Jenkins, 1980).

If systems are supersaturated with calcium or other scaling-forming minerals, this scale that collects on the paper pads can become very hard and extremely difficult to remove from the evaporative pads without damage to the paper fibers, if allowed to continue scaling over large amounts of time. The scale accumulation will cause airflow restrictions through the evaporative pads.

Well water quality varies significantly across the state of Alabama. Some wells have high calcium, iron, fluoride, magnesium, sodium, or other minerals. Groundwater, during the summer, can experience an increase in water temperatures (Water Science School, 2018). As temperatures in groundwater increase, the water can dissolve more minerals from the surrounding rock and environment within the area. This can contribute to changes in the mineral concentration in the supply water from a well during the summer.

1.2 OBJECTIVE

The objective of this study was to quantify the formation of mineral scale on evaporative cooling pads using a farm well water source from a commercial broiler farm over a summer of production.

1.3 MATERIALS AND METHODS

1.3.1 WELL WATER SOURCE

Water was sourced from a commercial broiler farm in southeast Alabama. The farm has five groundwater wells that were plumbed into one pump house. In the pump house, water was pumped through a large volume water filter (BBC-150, Watt, North Andover, MA) before being pumped to each poultry house. Water collected for this study was drawn from the pump house after the filter through a 51 mm (2 in.) ball valve. Four 1,250 L (330 gals) IBC tanks (H-4420, Uline, Pleasant Praire, WI) were filled with well water and transported from south-east Alabama back to the National Poultry Technology Center (NPTC) in Auburn, Alabama, where the study was conducted. A total of seven water collection trips were performed during the study: 07 July 2022, 19 July 2022, 29 July 2022, 08 August 2022, 17 August 2022, 30 August 2022, and 14 September 2022.

1.3.2 EVAPORATIVE COOLING TEST STANDS

Four commercially available evaporative cooling systems (PACJS2601A1, Portacool, Center, TX) were used as test stands (fig. 1). Each evaporative cooling system was labeled (A, B, C, D). Each system held five paper evaporative pads (PARKULJ26000, Portacool, Center, TX) with dimensions of 0.60 m x 1.20 m x 0.15 m (12 in x 48 in x 6 in.). The flow rate over the pads was checked manually with a catch trough and the water weighed with scales (TD52P, Ohaus, Parsippany, NJ). Flow rates for each system ranged between 0.33 L s⁻¹ to 0.34 L s⁻¹ (5.2 gal min⁻¹

to 5.4 gal min^{-1}), exceeding the pad manufacturer's minimum required flow rate of 0.14 L s^{-1} (2.2 gal min^{-1}) (Kuul, 2017). Each system was equipped with a 227 L (60 gal) sump tank. A stationary 1250 L (330 gal) IBC tank was plumbed into each system to supply water to the sump. A fountain pump (84577, Geoglobal Partners, West Palm Beach, FL) was submerged in each stationary IBC tank to keep the water agitated and mineral suspended. The IBC tank was plumbed into a 38 mm (1.5 in.) PVC check valve. The check valve kept the pressure constant between the valve and pump to prevent pump cycling. A 373 watts (0.5 hp) shallow well jet pump (AUTOJ100A2, Everbilt, Atlanta, GA) was used to pump the water into the evaporative cooling system. On the exit side of the pump, a tee was used to plumb one ball valve to take water samples and one ball valve to fill the sump. The second ball valve going to the evaporative system was plumbed into a 1.22 m (4 ft) by 19 mm (0.75 in.) water hose (HH56412-4FF, Hog Slats, Newton Grove, NC). The water hose was plumbed into a 51 mm (2 in.) by 0.61 m (2 ft) tall capped- PVC air chamber used to prevent cavitation. Next, a 1.22 m (4 ft) water hose was connected to a water meter (Mach 10, Neptune, Tallassee, AL) and then to a 15.24 m (50 ft) by 16 mm (5/8 in.) water hose (8882-50, Teknor apex, Pawtucket, RI) fixed to the system shut off valve. Each sump was manually filled to 227 L (60 gal) and then topped off every 57 – 76 L (15-20 gal) as the water was evaporated from the system.



Figure 1: Four portable evaporative cooling systems fitted with new paper pads. Stationary IBC tanks were plumbed into each evaporative system through a pump and water meter. The yellow arrow is pointing at the supply water sampling ball valve.

1.3.3 DATA COLLECTION AND WATER SAMPLES

1.3.3.1 Supply and sump water sampling

Two 500 mL water samples were collected in containers (89094-116, VWR International, Radnor, PA) at the beginning and halfway through filling each IBC tank on the poultry farm for a total of eight water samples per water collection event (56 samples across summer). 500 ml water samples were collected with the same containers while initially filling the 227 L (60 gal) sump and then every 75.7 L (20 gal) of evaporative water for the study duration (101 samples per system). A total of 7571 L (2000 gal) was evaporated in each of the four systems. A bleed-off rate or sump empty schedule was not used in this study during the water being evaporated. All water samples were analyzed by the University of Georgia Extension Soil and Water Testing Center for

a W2 water analysis that included a basic mineral water test, anions, soluble salts, and alkalinity.

1.3.3.2 Evaporative Pad Scale

The pads in each evaporative cooling system had individual labels written in permanent marker (system A: A1, A2, A3, A4, A5), starting from left to right. Each individual pad was initially weighed with a scale (TD52P, Ohaus, Parsippany, NJ) and then at each 757 L (200 gal) increment. Moisture content was taken with a moisture meter (RDM3P, Delmhorst Instrument Co., Towaco, NJ) at six locations along the pad at the beginning and then every 757 L (200 gal) to calculate pad dry weight.

A differential pressure gauge (Magnehelic, Dwyer Instruments, INC, Michigan City, IN) was mounted to the side of the evaporative system (fig. 2). A 6.4 mm (0.25 in.) hose connected the pressure gauge negative port to the system housing, with the positive port exposed externally. Pressure readings were collected after pads were dried in the system at the beginning and every 757 L (200 gal).

During the study, the fan and pump were turned on and allowed to run continuously during the day. Each fan was set to the maximum setting, ranging from 618 to 625 RPMs. After every 757 L (200 gal) evaporated, the sump pump was turned off, and the fan was left running to dry the pads. Pressure across the pads were recorded for dry pads. The fan was turned off, and the evaporative pads were removed from the system. Once the pads were removed, a 500 mL water sample was taken from each sump. The pads were taken inside a temperature-controlled building and allowed to continue drying for 12 hr. The moisture content and pad weights were measured and recorded. Evaporative pads were placed back in the system, and the process was repeated.



Figure 2: Pressure across the pads was taken with a differential pressure gauge mounted to the side of the unit. The yellow arrow indicates the negative pressure port location.

1.3.4 STATISTICAL ANALYSIS

The four evaporative cooling systems served as experimental units in a completely randomized design. During water collection events, the effect of the collection event on water quality parameters was analyzed as a one-way ANOVA using the GLIMMIX procedure of SAS

(ver. 9.4, SAS, Cary, NC). During evaporative cooling operation, the effect of evaporation water consumption on water quality parameters in the i) source water entering the sump and ii) the concentrated sump water was analyzed as one-way ANOVA using the GLIMMIX procedure of SAS. Accumulated mineral scale on the evaporative cooling pads as a function of evaporation water consumption was analyzed as a one-way ANOVA with the GLIMMIX procedure of SAS. Means were separated at $P \leq 0.05$ with the PDIFF option.

1.4 RESULTS AND DISCUSSION

Seven water collection events were collected across one summer. Table 1 summarizes parameter concentrations for the collection events. Water quality parameters important to scaling that are significantly different were alkalinity, calcium, carbon dioxide, conductivity, magnesium, and sodium were different ($P < 0.0001$) as well as pH ($P < 0.0002$) over the seven events.

Alkalinity, calcium, and magnesium mean concentrations decrease over seven water collections. Carbon dioxide, conductivity, and pH mean concentration varied across the seven water samples. Sodium mean concentration increased over the seven water samples.

Table 1: Water quality parameters for seven sampling events across one summer.

Parameter	Units	Collection Events																				
		1			2			3			4			5			6			7		
		July 7, 2022			July 19, 2022			July 29, 2022			August 8, 2022			August 17, 2022			August 30, 2022			September 14, 2022		
		Mean	±	SEM	Mean	±	SEM	Mean	±	SEM	Mean	±	SEM	Mean	±	SEM	Mean	±	SEM	Mean	±	SEM
Alkalinity	ppm	175.50	±	1.354 ^a	174.81	±	0.296 ^a	175.42	±	0.272 ^a	154.73	±	2.664 ^b	145.15	±	3.933 ^b	148.59	±	3.675 ^b	150.80	±	3.656 ^b
Aluminum	ppm	0.10	±	0.000 ^a	0.10	±	0.003 ^a	0.10	±	0.000 ^a	0.10	±	0.000 ^a	0.10	±	0.000 ^a	0.10	±	0.000 ^a	0.10	±	0.000 ^a
Boron	ppm	0.01	±	0.001 ^{cd}	0.02	±	0.000 ^{cd}	0.01	±	0.000 ^d	0.04	±	0.003 ^{ab}	0.04	±	0.004 ^{ab}	0.05	±	0.007 ^a	0.03	±	0.005 ^{bc}
Calcium	ppm	67.88	±	0.828 ^{ab}	72.07	±	0.252 ^a	58.82	±	0.314 ^b	38.15	±	4.101 ^c	39.90	±	3.040 ^c	38.73	±	3.898 ^c	36.60	±	3.345 ^c
Carbon Dioxide	ppm	2.50	±	0.192 ^a	1.81	±	0.034 ^b	2.05	±	0.115 ^{ab}	1.78	±	0.044 ^b	1.89	±	0.079 ^b	1.71	±	0.082 ^b	1.98	±	0.107 ^b
Chromium	ppb	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a
Chloride	ppm	3.17	±	0.028 ^b	3.21	±	0.008 ^b	3.31	±	0.047 ^b	5.27	±	0.345 ^a	4.86	±	0.285 ^a	4.89	±	0.373 ^a	5.03	±	0.299 ^a
Conductivity	µS/cm	393.62	±	3.242 ^a	393.67	±	0.669 ^a	394.28	±	1.152 ^a	340.51	±	5.456 ^b	314.29	±	10.605 ^b	319.05	±	8.970 ^b	326.87	±	9.376 ^b
Copper	ppm	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a
Fluoride	ppm	0.15	±	0.000 ^a	0.15	±	0.000 ^a	0.15	±	0.000 ^a	0.15	±	0.000 ^a	0.15	±	0.000 ^a	0.15	±	0.000 ^a	0.15	±	0.000 ^a
Hardness		191.24	±	2.122 ^{ab}	203.04	±	0.753 ^a	165.25	±	0.791 ^b	113.37	±	10.720 ^c	117.58	±	8.089 ^c	115.03	±	10.081 ^c	108.22	±	8.635 ^c
Iron	ppm	0.12	±	0.008 ^a	0.11	±	0.006 ^a	0.11	±	0.007 ^a	0.10	±	0.000 ^a	0.10	±	0.000 ^a	0.10	±	0.000 ^a	0.10	±	0.000 ^a
Magnesium	ppm	5.82	±	0.035 ^a	5.61	±	0.051 ^a	4.47	±	0.016 ^b	4.40	±	0.184 ^b	4.36	±	0.161 ^b	4.45	±	0.159 ^b	4.09	±	0.140 ^b
Manganese	ppm	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a
Molybdenum	ppm	0.01	±	0.000 ^a	0.01	±	0.000 ^a	0.01	±	0.000 ^a	0.01	±	0.000 ^a	0.01	±	0.000 ^a	0.01	±	0.000 ^a	0.01	±	0.000 ^a
Nickle	ppb	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a
Nitrate	ppm	0.15	±	0.000 ^a	0.15	±	0.000 ^a	0.15	±	0.000 ^a	0.15	±	0.000 ^a	0.15	±	0.000 ^a	0.15	±	0.000 ^a	0.15	±	0.000 ^a
Phosphate	ppm	0.70	±	0.000 ^a	0.70	±	0.000 ^a	0.70	±	0.000 ^a	0.70	±	0.000 ^a	0.70	±	0.000 ^a	0.70	±	0.000 ^a	0.70	±	0.000 ^a
Potassium	ppm	1.60	±	0.056 ^c	2.02	±	0.050 ^b	1.54	±	0.044 ^c	2.06	±	0.026 ^b	1.56	±	0.111 ^c	2.00	±	0.119 ^b	3.38	±	0.032 ^a
Silicon	ppm	8.49	±	0.093 ^{abc}	8.71	±	0.137 ^{ab}	7.24	±	0.047 ^d	7.55	±	0.101 ^{cd}	8.20	±	0.374 ^{bc}	9.15	±	0.195 ^a	7.69	±	0.243 ^{cd}
Sodium	ppm	3.15	±	0.041 ^b	3.01	±	0.021 ^b	2.44	±	0.022 ^b	24.37	±	3.545 ^a	23.71	±	2.256 ^a	28.24	±	3.932 ^a	25.42	±	2.892 ^a
Sulfate	ppm	21.05	±	0.366 ^{ab}	23.40	±	0.106 ^a	23.39	±	0.094 ^a	17.53	±	0.820 ^{bc}	15.38	±	1.189 ^c	14.96	±	0.844 ^c	15.79	±	1.181 ^c
Zinc	ppm	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.10	±	0.014 ^a	0.09	±	0.026 ^a	0.05	±	0.001 ^a	0.06	±	0.009 ^a
Phosphorus	ppm	0.02	±	0.000 ^a	0.02	±	0.000 ^a	0.02	±	0.000 ^a	0.02	±	0.000 ^a	0.02	±	0.000 ^a	0.02	±	0.000 ^a	0.02	±	0.000 ^a
pH		8.16	±	0.030 ^c	8.29	±	0.008 ^a	8.24	±	0.025 ^{abc}	8.24	±	0.011 ^{abc}	8.19	±	0.009 ^{bc}	8.24	±	0.017 ^{ab}	8.19	±	0.019 ^{bc}

*abc letters within row are significantly different

*SEM= Standard Error of the Mean

Table 2 summarizes the water parameter concentrations for the water supply, from zero to 7571 L (2000 gal), of water consumed. The supply water parameter concentrations collected had a similar trend to the seven collection events. The important parameters to scale formation that were significantly different are alkalinity, calcium, carbon dioxide, conductivity, magnesium, and sodium ($P < 0.0001$), along with pH ($P = 0.0003$) across water consumption. Alkalinity, carbon dioxide, magnesium and pH mean concentrations varied over the supply water samples. Calcium mean concentration decreased over time. Conductivity mean concentration decreased until 7571 L and it increased again. Sodium mean concentration increased over the supply water samples.

Table 2: Water quality parameters for the supply water entering the evaporative system.

Parameter	Units	Water Evaporated (L)																					
		0		757		1514		2271		3028		3785		4542		5300		6057		6814		7571	
		Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Alkalinity	ppm	164.16 ± 4.052 ^a		152.2 ± 3.215 ^{ab}		134.36 ± 4.148 ^c		142.62 ± 1.906 ^{bc}		131.16 ± 2.172 ^c		140.11 ± 1.920 ^{bc}		129.37 ± 1.415 ^c		133.9 ± 2.336 ^c		133.62 ± 2.766 ^c		130.84 ± 2.017 ^c		141.22 ± 3.544 ^{bc}	
Aluminum	ppm	0.1 ± 0.000 ^{ab}		0.1054 ± 0.003 ^a		0.1 ± 0.000 ^{ab}		0.1017 ± 0.002 ^{ab}		0.1 ± 0.000 ^{ab}		0.1 ± 0.000 ^{ab}		0.1003 ± 0.000 ^{ab}		0.1064 ± 0.004 ^a		0.1 ± 0.000 ^{ab}		0.07097 ± 0.010 ^{bc}		0.053 ± 0.019 ^c	
Boron	ppm	0.01 ± 0.000 ^c		0.01478 ± 0.000 ^c		0.01098 ± 0.000 ^c		0.0125 ± 0.000 ^c		0.0177 ± 0.000 ^{bc}		0.03548 ± 0.003 ^a		0.03755 ± 0.004 ^a		0.03935 ± 0.005 ^a		0.03638 ± 0.002 ^a		0.04019 ± 0.003 ^a		0.03063 ± 0.005 ^{ab}	
Calcium	ppm	61.6088 ± 1.694 ^a		59.5856 ± 1.448 ^{ab}		45.701 ± 1.784 ^{cde}		52.973 ± 0.918 ^{abc}		52.1179 ± 1.071 ^{abc}		42.4061 ± 2.772 ^{cde}		35.5694 ± 1.937 ^e		36.4648 ± 2.134 ^{de}		35.1855 ± 3.532 ^e		35.1751 ± 2.772 ^e		48.0095 ± 4.412 ^{cde}	
Carbon Dioxide	ppm	1.8312 ± 0.162 ^a		1.6618 ± 0.069 ^{ab}		1.3875 ± 0.097 ^{bc}		1.6711 ± 0.064 ^{ab}		1.6487 ± 0.071 ^{ab}		1.3954 ± 0.041 ^{bc}		1.2799 ± 0.041 ^{bc}		1.2155 ± 0.062 ^c		1.221 ± 0.069 ^c		1.2782 ± 0.034 ^{bc}		1.46 ± 0.104 ^{abc}	
Chromium	ppb	10 ± 0.000 ^{ab}		10.325 ± 0.325 ^a		10 ± 0.000 ^{ab}		10 ± 0.000 ^{ab}		10 ± 0.000 ^{ab}		10.375 ± 0.375 ^a		10 ± 0.000 ^{ab}		10 ± 0.000 ^{ab}		10.0625 ± 0.063 ^{ab}		7.0833 ± 0.986 ^{bc}		4.3 ± 1.902 ^c	
Chloride	ppm	3.233 ± 0.029 ^b		3.1945 ± 0.015 ^b		3.287 ± 0.009 ^b		3.2645 ± 0.006 ^b		8.5398 ± 0.982 ^a		4.6185 ± 0.177 ^b		4.632 ± 0.192 ^b		4.6545 ± 0.230 ^b		4.7522 ± 0.215 ^b		4.8002 ± 0.267 ^b		4.2215 ± 0.361 ^b	
Conductivity	µS/cm	370.04 ± 8.913 ^a		343.05 ± 6.468 ^{ab}		306.07 ± 7.436 ^{cd}		318.79 ± 3.715 ^{bc}		361.29 ± 6.640 ^a		313.82 ± 4.639 ^{bcd}		289.89 ± 1.358 ^{cd}		290.44 ± 5.209 ^{cd}		290.2 ± 5.665 ^{cd}		287.17 ± 3.690 ^d		315.17 ± 10.360 ^{bcd}	
Copper	ppm	0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.03142 ± 0.006 ^b		0.01778 ± 0.011 ^b	
Fluoride	ppm	0.15 ± 0.000 ^b		0.15 ± 0.000 ^b		0.15 ± 0.000 ^b		0.15 ± 0.000 ^b		0.2652 ± 0.049 ^a		0.15 ± 0.000 ^b		0.15 ± 0.000 ^b		0.15 ± 0.000 ^b		0.15 ± 0.000 ^b		0.15 ± 0.000 ^b		0.15 ± 0.000 ^b	
Hardness		173.82 ± 4.256 ^a		170.06 ± 3.687 ^{ab}		132.52 ± 4.524 ^{cdef}		152.85 ± 2.336 ^{abcd}		158.66 ± 3.632 ^{abc}		126.07 ± 7.357 ^{def}		107.36 ± 5.343 ^{ef}		109.75 ± 5.943 ^{ef}		105.24 ± 9.960 ^f		105.82 ± 7.728 ^f		139.57 ± 11.650 ^{bcd}	
Iron	ppm	0.1028 ± 0.002 ^a		0.1068 ± 0.005 ^a		0.1002 ± 0.000 ^a		0.1002 ± 0.000 ^a		0.1 ± 0.000 ^a		0.1 ± 0.000 ^a		0.1 ± 0.000 ^a		0.1 ± 0.000 ^a		0.1 ± 0.000 ^a		0.07294 ± 0.010 ^a		0.0377 ± 0.021 ^b	
Magnesium	ppm	4.8521 ± 0.015 ^{cb}		5.1665 ± 0.025 ^b		4.4747 ± 0.021 ^{cb}		4.9956 ± 0.012 ^{cb}		6.9263 ± 0.332 ^a		4.902 ± 0.114 ^{cb}		4.5036 ± 0.136 ^{cb}		4.5411 ± 0.175 ^{cb}		4.2221 ± 0.299 ^c		4.369 ± 0.232 ^{cb}		4.7815 ± 0.188 ^{cb}	
Manganese	ppm	0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.02936 ± 0.007 ^{ab}		0.01253 ± 0.012 ^b	
Molybdenum	ppm	0.01 ± 0.000 ^{ab}		0.01 ± 0.000 ^{ab}		0.01 ± 0.000 ^{ab}		0.01 ± 0.000 ^{ab}		0.0112 ± 0.001 ^a		0.01053 ± 0.001 ^{ab}		0.0114 ± 0.001 ^a		0.01 ± 0.000 ^{ab}		0.01 ± 0.000 ^{ab}		0.005944 ± 0.001 ^{bc}		0.002825 ± 0.002 ^c	
Nickle	ppb	10 ± 0.000 ^a		10 ± 0.000 ^a		10 ± 0.000 ^a		10 ± 0.000 ^a		10.1 ± 0.100 ^a		10 ± 0.000 ^a		10 ± 0.000 ^a		10 ± 0.000 ^a		10.0625 ± 0.063 ^a		7.5833 ± 0.859 ^{ab}		5.475 ± 1.652 ^b	
Nitrate	ppm	0.15 ± 0.000 ^b		0.15 ± 0.000 ^b		0.15 ± 0.000 ^b		0.15 ± 0.000 ^b		0.1742 ± 0.009 ^a		0.15 ± 0.000 ^b		0.15 ± 0.000 ^b		0.15 ± 0.000 ^b		0.15 ± 0.000 ^b		0.15 ± 0.000 ^b		0.15 ± 0.000 ^b	
Phosphate	ppm	0.7 ± 0.000 ^a		0.7 ± 0.000 ^a		0.7 ± 0.000 ^a		0.7 ± 0.000 ^a		0.7 ± 0.000 ^a		0.7 ± 0.000 ^a		0.7 ± 0.000 ^a		0.7 ± 0.000 ^a		0.7 ± 0.000 ^a		0.7 ± 0.000 ^a		0.7 ± 0.000 ^a	
Potassium	ppm	1.8857 ± 0.044 ^b		1.6841 ± 0.021 ^b		1.5951 ± 0.067 ^b		2.1597 ± 0.020 ^b		3.1202 ± 0.181 ^a		1.4957 ± 0.046 ^b		1.8162 ± 0.018 ^b		2.026 ± 0.060 ^b		2.1834 ± 0.396 ^b		2.0144 ± 0.224 ^b		1.9668 ± 0.110 ^b	
Silicon	ppm	8.5849 ± 0.040 ^{bcd}		8.5683 ± 0.038 ^{bcd}		7.3768 ± 0.032 ^e		7.8785 ± 0.022 ^{de}		9.7796 ± 0.299 ^a		8.3343 ± 0.028 ^{bcd}		8.0868 ± 0.063 ^{cde}		8.9368 ± 0.126 ^{ab}		8.6308 ± 0.315 ^{bcd}		8.9316 ± 0.284 ^{bc}		8.9615 ± 0.191 ^{ab}	
Sodium	ppm	2.9113 ± 0.119 ^c		2.8872 ± 0.042 ^c		2.5046 ± 0.015 ^c		2.7796 ± 0.015 ^c		9.0332 ± 0.890 ^{bc}		18.6908 ± 2.360 ^{ab}		20.4363 ± 2.333 ^a		22.5839 ± 2.562 ^a		23.9931 ± 2.233 ^a		23.5477 ± 2.937 ^a		15.4303 ± 4.184 ^{ab}	
Sulfate	ppm	20.7217 ± 0.652 ^{bcd}		21.8815 ± 0.600 ^{bc}		23.0378 ± 0.182 ^b		23.283 ± 0.068 ^b		36.2245 ± 2.325 ^a		19.4585 ± 0.835 ^{bcd}		18.1038 ± 0.956 ^{bcd}		16.666 ± 1.171 ^{cd}		15.9449 ± 1.173 ^d		16.2865 ± 1.125 ^d		19.0558 ± 1.252 ^{bcd}	
Zinc	ppm	0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.1257 ± 0.076 ^a		0.05 ± 0.000 ^a		0.05159 ± 0.001 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.05 ± 0.000 ^a		0.03736 ± 0.004 ^a		0.02455 ± 0.009 ^a	
Phosphorus	ppm	0.021 ± 0.001 ^a		0.0201 ± 0.000 ^a		0.02 ± 0.000 ^a		0.02045 ± 0.000 ^a		0.02005 ± 0.000 ^a		0.0206 ± 0.000 ^a		0.02 ± 0.000 ^a		0.02003 ± 0.000 ^a		0.02 ± 0.000 ^a		0.07692 ± 0.061 ^a		0.01698 ± 0.002 ^a	
pH		8.2592 ± 0.032 ^{abc}		8.2653 ± 0.012 ^{abc}		8.2915 ± 0.019 ^{abc}		8.2345 ± 0.011 ^{bc}		8.2013 ± 0.012 ^c		8.306 ± 0.009 ^{ab}		8.3068 ± 0.019 ^{ab}		8.3448 ± 0.026 ^a		8.3426 ± 0.029 ^a		8.3148 ± 0.017 ^{ab}		8.2922 ± 0.019 ^{abc}	

*abc letters within row are significantly different

*SEM= Standard Error of the Mean

Table 3 summarizes the water parameter concentrations for the sump water from zero to 7571 L (2000 gal) of water consumption. The sump parameters that are important to potential scaling and significantly different in the sump measurements were alkalinity ($P < 0.0001$), calcium ($P < 0.0001$), carbon dioxide ($P = 0.0282$), conductivity ($P = 0.0003$), magnesium ($P < 0.0001$), sodium ($P < 0.0001$), and pH ($P < 0.0001$). Alkalinity, calcium, and carbon dioxide mean concentrations varied over the sump water samples. Conductivity mean concentration increased over the sump water samples. Magnesium mean concentration increased until 3785 L then it started decreasing over the sump water samples. Sodium and pH mean concentration increased over the sump water samples.

Table 3: Water quality parameters for the sump water in the evaporative system.

Parameter	Units	Water Evaporated (L)																													
		757 L			1514 L			2271 L			3028			3785			4542			5300			6057			6814			7571		
		Mean	±	SEM	Mean	±	SEM	Mean	±	SEM	Mean	±	SEM	Mean	±	SEM	Mean	±	SEM	Mean	±	SEM	Mean	±	SEM	Mean	±	SEM	Mean	±	SEM
Alkalinity	ppm	207.85	±	2.836 ^{bcd}	196.55	±	7.991 ^{cd}	190.32	±	6.954 ^{cd}	185.84	±	5.207 ^d	217.78	±	1.918 ^{abcd}	232.25	±	5.727 ^{abcd}	274.65	±	9.853 ^{ab}	260.61	±	15.34 ^{abc}	286.80	±	35.517 ^a	261.13	±	35.517 ^{abc}
Aluminum	ppm	0.10	±	0.003 ^a	0.10	±	0.002 ^{ab}	0.10	±	0.000 ^{ab}	0.10	±	0.000 ^{ab}	0.10	±	0.000 ^{ab}	0.10	±	0.000 ^{ab}	0.11	±	0.015 ^a	0.1	±	0.00 ^{ab}	0.06	±	0.021 ^b	0.10	±	0.000 ^{ab}
Boron	ppm	0.02	±	0.002 ^e	0.02	±	0.001 ^e	0.03	±	0.002 ^e	0.05	±	0.004 ^{de}	0.09	±	0.002 ^{cd}	0.13	±	0.005 ^{abc}	0.14	±	0.006 ^{ab}	0.1065	±	0.01 ^{bc}	0.17	±	0.021 ^a	0.16	±	0.144 ^a
Calcium	ppm	61.87	±	2.421 ^{ab}	63.20	±	3.300 ^{ab}	69.26	±	3.709 ^{ab}	74.68	±	3.276 ^a	62.06	±	4.181 ^{ab}	50.08	±	4.359 ^{bc}	50.97	±	4.463 ^{bc}	38.3145	±	3.99 ^c	37.72	±	5.212 ^c	36.22	±	4.217 ^c
Carbon Dioxide	ppm	2.14	±	0.325 ^a	1.77	±	0.195 ^a	2.10	±	0.252 ^a	2.10	±	0.195 ^a	1.57	±	0.161 ^a	1.59	±	0.033 ^a	1.45	±	0.051 ^a	1.9197	±	0.08 ^a	1.49	±	0.086 ^a	1.59	±	0.065 ^a
Chromium	ppb	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10	±	0.00 ^a	6.00	±	2.309 ^b	10.00	±	0.000 ^a
Chloride	ppm	49.36	±	6.404 ^{bc}	44.98	±	6.980 ^c	54.43	±	9.056 ^{abc}	64.74	±	9.423 ^{abc}	86.41	±	7.872 ^{ab}	78.05	±	8.009 ^{abc}	87.21	±	9.037 ^a	67.0525	±	4.92 ^{abc}	89.37	±	2.581 ^a	72.15	±	9.609 ^{abc}
Conductivity	µS/cm	927.69	±	60.570 ^c	891.52	±	105.046 ^c	997.52	±	96.282 ^{bc}	978.07	±	55.038 ^{bc}	1200.57	±	44.823 ^{abc}	1165.02	±	69.269 ^{abc}	1318.49	±	79.356 ^{ab}	1187.52	±	49.75 ^{abc}	1345.79	±	80.429 ^a	1205.49	±	43.307 ^{abc}
Copper	ppm	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.00 ^a	0.03	±	0.014 ^b	0.05	±	0.000 ^a
Fluoride	ppm	2.78	±	0.598 ^a	1.96	±	0.396 ^{ab}	1.90	±	0.487 ^{abc}	1.84	±	0.449 ^{abc}	0.76	±	0.097 ^{bc}	0.60	±	0.103 ^{bc}	0.58	±	0.087 ^{bc}	0.41	±	0.04 ^c	0.49	±	0.070 ^{bc}	0.42	±	0.021 ^c
Hardness		198.94	±	7.049 ^b	213.67	±	13.846 ^{ab}	257.27	±	19.380 ^{ab}	304.51	±	21.346 ^a	308.79	±	23.372 ^a	255.62	±	28.363 ^{ab}	253.70	±	29.126 ^{ab}	173.81	±	19.82 ^b	180.26	±	21.281 ^b	161.94	±	19.537 ^b
Iron	ppm	0.10	±	0.000 ^a	0.10	±	0.000 ^a	0.10	±	0.000 ^a	0.10	±	0.000 ^a	0.10	±	0.000 ^a	0.10	±	0.000 ^a	0.10	±	0.000 ^a	0.1	±	0.00 ^a	0.05	±	0.028 ^b	0.10	±	0.000 ^a
Magnesium	ppm	10.79	±	0.568 ^c	13.57	±	1.370 ^c	20.48	±	2.549 ^{bc}	28.66	±	3.202 ^{ab}	37.36	±	3.311 ^a	31.71	±	4.442 ^{ab}	30.70	±	4.577 ^{ab}	18.9743	±	2.78 ^{bc}	20.90	±	2.314 ^{bc}	17.36	±	2.574 ^{bc}
Manganese	ppm	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.00 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a
Molybdenum	ppm	0.01	±	0.000 ^a	0.01	±	0.000 ^a	0.01	±	0.000 ^a	0.01	±	0.000 ^a	0.01	±	0.000 ^a	0.01	±	0.000 ^a	0.01	±	0.000 ^a	0.01	±	0.00 ^a	0.01	±	0.002 ^b	0.01	±	0.000 ^a
Nickle	ppb	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10.00	±	0.000 ^a	10	±	0.00 ^a	6.00	±	2.449 ^b	10.00	±	0.000 ^a
Nitrate	ppm	0.32	±	0.067 ^b	0.40	±	0.047 ^{ab}	0.37	±	0.098 ^{ab}	0.49	±	0.103 ^{ab}	0.75	±	0.126 ^{ab}	0.61	±	0.108 ^{ab}	0.78	±	0.156 ^{ab}	0.61	±	0.11 ^{ab}	0.86	±	0.093 ^a	84.00	±	0.118 ^a
Phosphate	ppm	0.70	±	0.000 ^a	0.70	±	0.000 ^a	0.70	±	0.000 ^a	0.70	±	0.000 ^a	0.70	±	0.000 ^a	0.70	±	0.000 ^a	0.70	±	0.000 ^a	0.7	±	0.00 ^a	0.70	±	0.000 ^a	0.70	±	0.000 ^a
Potassium	ppm	7.23	±	0.420 ^c	9.10	±	0.934 ^c	13.98	±	1.786 ^{bc}	19.49	±	2.008 ^{ab}	26.60	±	1.399 ^a	24.83	±	1.941 ^a	27.53	±	2.998 ^a	19.8358	±	1.74 ^{ab}	25.82	±	1.367 ^a	21.40	±	2.697 ^{ab}
Silicon	ppm	16.20	±	0.950 ^b	16.77	±	1.402 ^{ab}	21.83	±	2.380 ^{ab}	26.14	±	3.013 ^a	26.38	±	2.812 ^a	23.76	±	2.444 ^{ab}	25.15	±	1.830 ^{ab}	18.275	±	1.50 ^{ab}	22.42	±	1.430 ^{ab}	21.60	±	1.707 ^{ab}
Sodium	ppm	58.15	±	4.398 ^c	46.33	±	5.259 ^c	60.22	±	8.701 ^c	73.54	±	7.814 ^c	135.54	±	1.243 ^b	153.14	±	10.950 ^{ab}	184.20	±	8.726 ^{ab}	136.01	±	11.67 ^b	209.85	±	27.915 ^a	177.32	±	18.166 ^{ab}
Sulfate	ppm	76.54	±	5.610 ^d	101.53	±	12.797 ^{cd}	139.88	±	19.986 ^{bcd}	183.55	±	23.389 ^{abc}	248.01	±	16.327 ^a	224.89	±	22.880 ^{ab}	265.91	±	29.191 ^a	194.57	±	22.24 ^{abc}	260.05	±	12.909 ^a	220.42	±	34.080 ^{ab}
Zinc	ppm	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.000 ^a	0.05	±	0.00 ^a	0.03	±	0.014 ^b	0.05	±	0.000 ^a
Phosphorus	ppm	0.02	±	0.000 ^b	0.02	±	0.000 ^b	0.02	±	0.000 ^b	0.02	±	0.000 ^b	0.02	±	0.000 ^b	0.02	±	0.000 ^b	0.02	±	0.000 ^b	0.02	±	0.00 ^b	0.03	±	0.012 ^{ab}	0.05	±	0.000 ^a
pH		8.31	±	0.075 ^{bc}	8.35	±	0.050 ^{abc}	8.27	±	0.056 ^c	8.25	±	0.034 ^c	8.45	±	0.042 ^{abc}	8.47	±	0.016 ^{abc}	8.58	±	0.015 ^a	8.4325	±	0.03 ^{abc}	8.58	±	0.076 ^a	8.51	±	0.052 ^{ab}

*abc letters within row are significantly different

*SEM= Standard Error of the Mean

Figure 3 shows scale that accumulated on the evaporative pads at each 757 L (200 gal) consumed. The water that was in the sump was never emptied or bled off during this study. Calcium concentration of the supply water samples were included for comparison. In general, scale formation was proportional to calcium concentration. There were two water consumption points during the summer that didn't follow the trend (5300 and 6057L). These points developed scale higher than the calcium concentration trend. Calcium was not the only mineral in this water. Other minerals could have contributed to some of the scale accumulation. This well water source developed scale at a rate of 168 g per 1000 L of water evaporated.

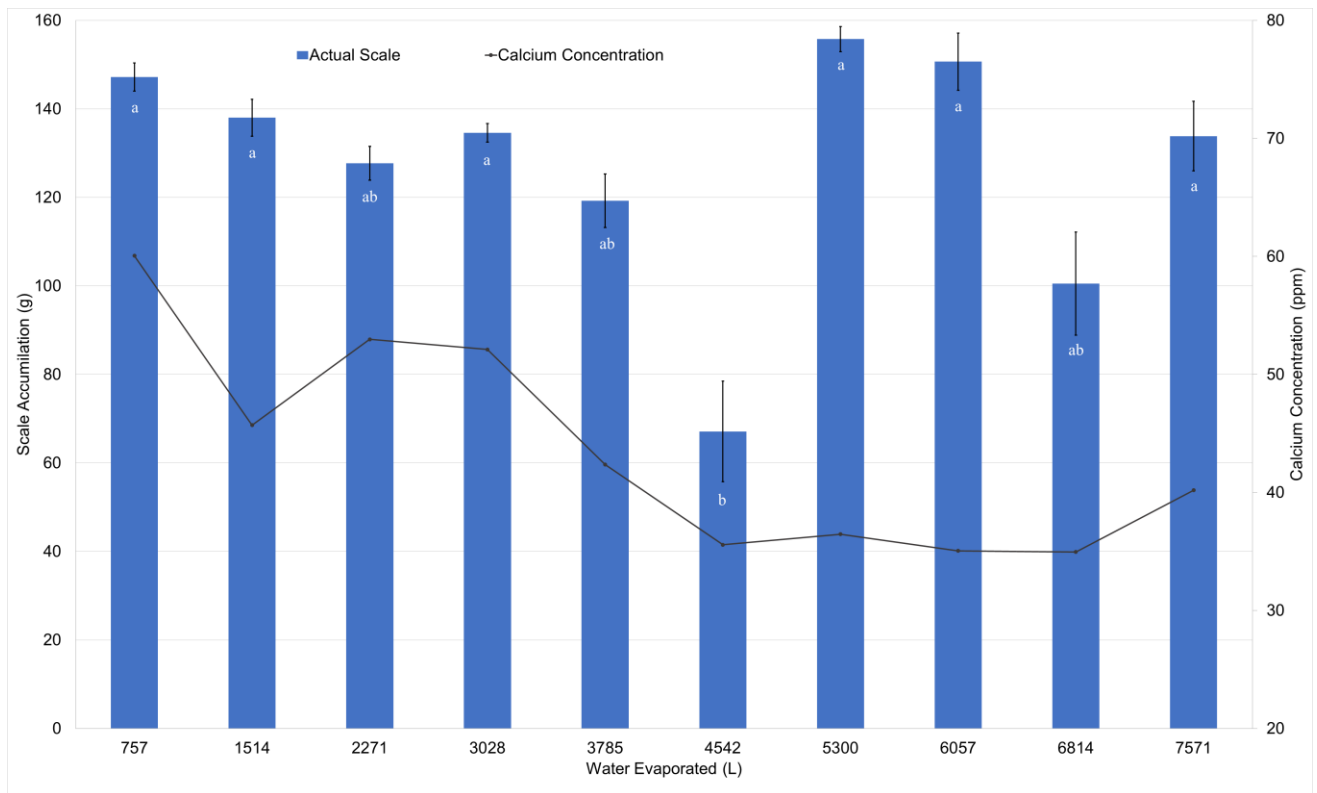


Figure 3: The actual scale that accumulated on pads and calcium concentration in the supply water samples is included for comparison.

The calcium concentration in the sump was higher than the calcium concentration in the supply water for all sample points except at the end of the study (fig. 4). This shows that the concentration of calcium does increase in the sump as the water is evaporated from the system. The level of increase may have been lessened if the system had been periodically dumped or

bleed-off per manufacturer directions.

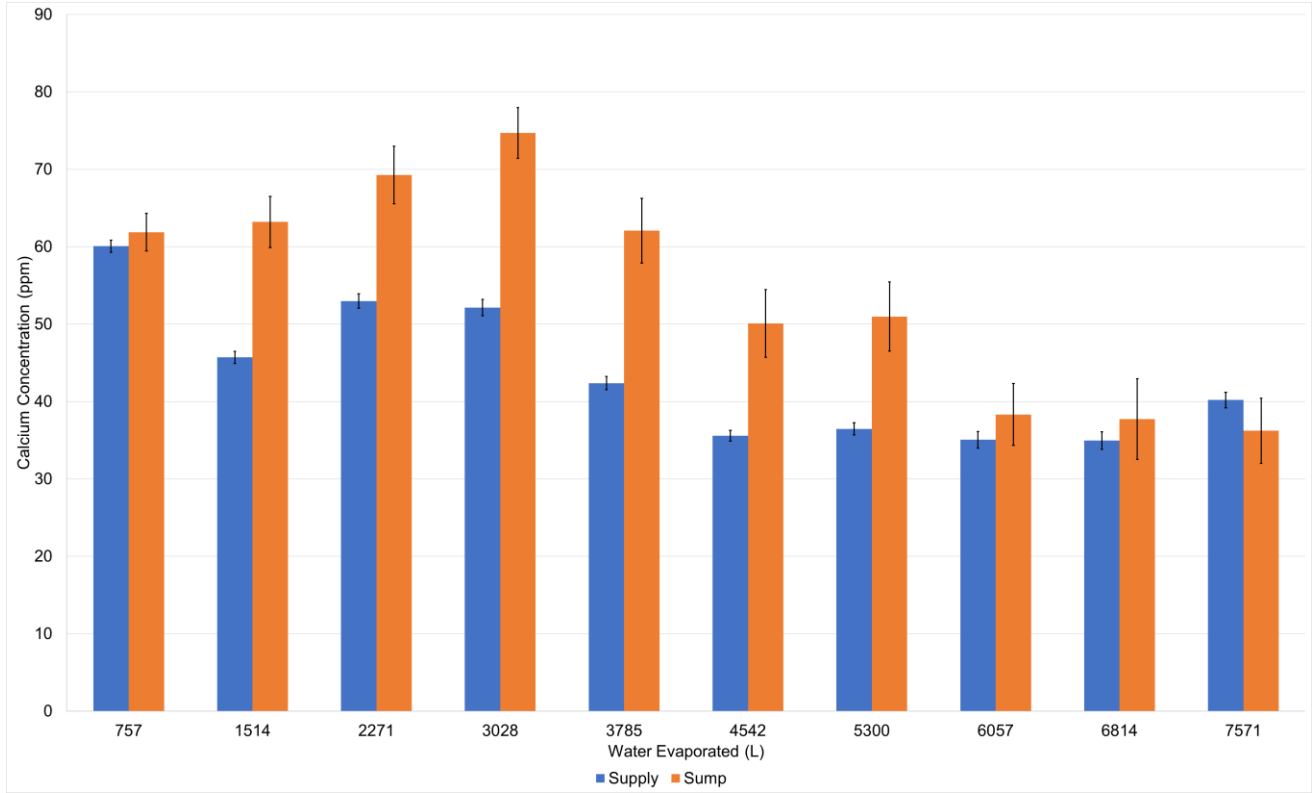


Figure 4: Calcium concentration of supply water and sump water over 7571 L (2000 gal) of water evaporated.

Static pressure varied slightly across the summer but was not different ($P=0.63$) (fig. 5).

Some of the variation could be contributed to the measurement being taken outside in the open air with wind gusts causing some small fluctuations in the measurements. This well water source did not affect the static pressure with the development of scale over a summer of operation without bleed-off.

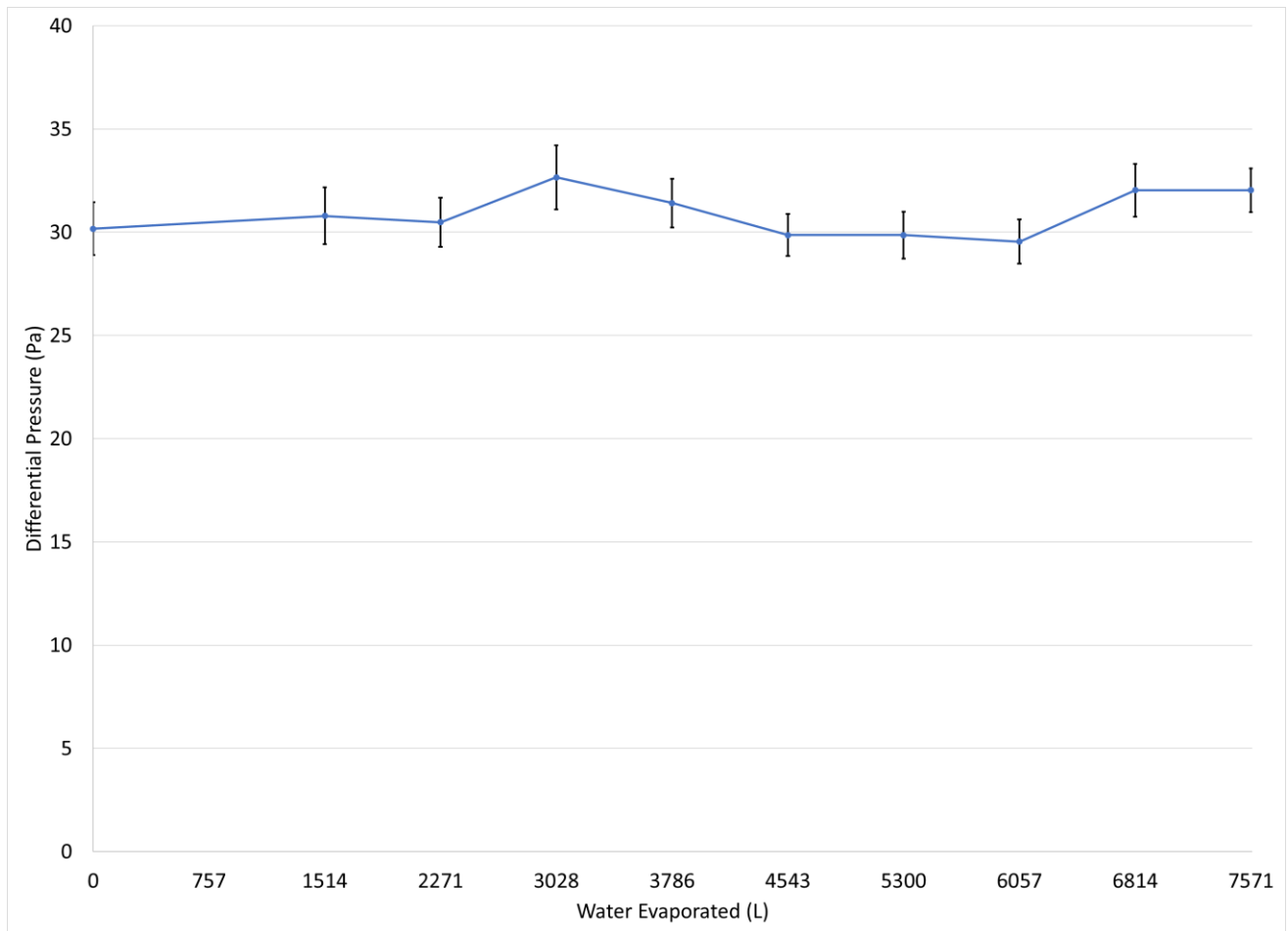


Figure 5: Differential pressure measured across the evaporative cooling pads (n=4) over the duration of the study.

To provide some perspective, the scale accumulation for this farm well water source can be estimated for a commercial broiler farm. One 18 x 183 m (60 x 600 ft) poultry house uses roughly 88,000 L (23,300 gal) of water per flock per evaporative cooling system on each side of the house. Over ten years using the evaporative pads for three flocks each year (30 flocks), the evaporative pads would accumulate 3700 g per pad (8 lbs. per pad). This value does not account for additional dirt and debris that typically accumulates in pads. This extra dirt and debris add more surface area for calcium to attach, and as the water flows over the pads, scale and debris get caught in the pads, increasing the rate of scale formation within the system. Any impurities with surface area increase the scaling rate of water because it is easier for the scale to attach to the

pads. The farm that operates on the well water source used in this study had pads in operation that had accumulated 6 kg to 11 kg (14 lbs. to 25 lbs.) of scale.

1.5 CONCLUSION

- A test stand and procedure were developed that allowed the comparison of scale formation on evaporative pads with replicated units. This can be used with other well water sources to get the rate of scaling expected when the parameter concentrations are different.
- Over a summer of evaporative cooling, it was found that some of the water quality parameters changed. When evaluating scale accumulation, it may be important to measure water quality at more than one point in time.
- Calcium concentration in the sump water was consistently higher than the supply water as we did not bleed-off or empty the system.
- The scaling rate for this well water source was 168 g per 1000 L of water evaporated. This rate may be used to predict minimum scaling that would happen on the farm over a summer of use.

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Chapter 2: Study 1

2.1 INTRODUCTION

Evaporative cooling systems are used during the summer to keep broiler birds at comfortable temperatures on commercial poultry farms. The systems have engineered cellulose pads that work using adiabatic cooling through the evaporation of water passing over the pads. Well water is often used to supply the water to the evaporative system. Well water quality can vary widely. In Alabama, we have producers facing water quality challenges with iron, calcium, sodium, fluoride, and other minerals from the aquifers.

During the summer in Alabama, the temperatures outside are 35°C (95°F) or higher during the day, the evaporative system can run up to 10 hr to 8 hr daily. During this time period, the evaporative pads can evaporate 458 L pad⁻¹ to 1026 L pad⁻¹ of water (121 gal pad⁻¹ to 271 gal pad⁻¹) (Carson Edge, Auburn University, personal communication, May 2021).

Evaporative cooling systems operate using a recirculating and top-off method. As the water evaporates, the minerals in the water are left in the evaporative system. As water is continuously evaporated, the mineral content in the water gets more concentrated with minerals. This leads to nucleation, the first step of precipitation, finding a surface to attach to and grow. Once the minerals start precipitating on the pads, it will begin to attach to itself and grow as water is evaporated. This step is referred to as crystal growth. This is less stable precipitation and is the easiest for of mineral precipitation to remove from the pads. The final step is agglomeration and ripening, this happens when the pads are allowed to continue scaling without any maintenance to the pads. This state of scale precipitation is harder to remove from the evaporative pads without damaging the pads. If allowed to grow, the flutes in the pads can become clogged and restrict airflow. If the scale precipitation is left untreated, it can also affect

the wetting of the pads. Wetting can become localized and not evenly wet the pad causing parts of the system to cool inefficiently (Watt and Brown, 1997).

Over the past three years, evaporative pad costs have increased. To replace the evaporative pads in an 18 x 183 m (60 x 600 ft) poultry house in October 2022 the cost was \$5220 or \$21.75 per evaporative pad. In August 2023 the same amount of evaporative pads cost \$6240 or \$26.00 per evaporative pad. This continued increase in price is forcing producers to look for ways to help extend the life of their evaporative pads.

There are several chemical cleaning options commercially available for descaling evaporative pads on a poultry farm. With so many cleaner choices, poultry producers tend to struggle to decide which cleaner will work best with the problems occurring in the evaporative system. Many of the cleaners that are available for poultry producers to use on evaporative pads do not state on the label what problems it will target. Not all producers encounter the same evaporative pad problems. Some producers have various mineral issues, and some have algae growth problems. When the producer attempts to select a cleaner for the evaporative pads many times, it's a trial-and-error situation that leads to little improvement in the evaporative pads.

2.2 OBJECTIVE

The objective of this study was to quantify scale removal from paper evaporative cooling pads at two scale levels (minimal scaled from one summer and heavily scaled from five summers) using two water sources (well water and municipal).

2.3 MATERIALS AND METHODS

2.3.1 Water Sources

Two water sources were evaluated: a farm well water source and a municipal water source. The well water was sourced from a commercial broiler farm in southeast Alabama. The

farm has five groundwater wells that were plumbed to one pump house. In the pump house, water was pumped through a large volume water filter (BBC-150, Watt, North Andover, MA) before being pumped to each poultry house. The well water was pulled from the pump house after the filter through a 51 mm (2 in.) ball valve. Four 1,250 L (330 gals) IBC tanks (H-4420, Uline, Pleasant Praire, WI) were filled and transported from southeast Alabama back to the National Poultry Technology Center (NPTC) in Auburn, Alabama, where the study was conducted. A total of four water collection trips were performed during this study. The municipal water was sourced at the NPTC facility, with water being supplied by Loachapoka Water Authority. Water quality parameters for both well water and municipal water sources are summarized in table 1.

Table 4: Summary of well water and municipal water quality parameters

Parameter	Units	Water Source	
		Well water	Municipal
Alkalinity	ppm	136.99	27.31
Aluminum	ppm	0.10	0.54
Boron	ppm	0.08	0.01
Calcium	ppm	19.80	4.67
Carbon Dioxide	ppm	1.90	4.00
Chromium	ppb	10.00	10.00
Chloride	ppm	6.99	7.52
Conductivity	μS/cm	307.00	123.00
Copper	ppm	0.05	0.05
Fluoride	ppm	0.15	0.66
Hardness		67.20	17.90
Iron	ppm	0.13	1.72
Magnesium	ppm	4.33	1.52
Manganese	ppm	0.05	0.05
Molybdenum	ppm	0.01	0.01
Nickle	ppb	10.00	10.00
Nitrate	ppm	0.16	0.15
Phosphate	ppm	0.70	0.76
Potassium	ppm	2.25	2.19
Silicon	ppm	9.26	2.70
Sodium	ppm	48.40	17.50
Sulfate	ppm	15.01	18.70
Zinc	ppm	0.05	0.19
Phosphorus	ppm	0.02	0.55
pH		8.20	7.10

2.3.2 Scaled Pad Sources

Two levels of paper pad scaling were evaluated: minimal scaled and heavily scaled pads. The minimally scaled pads were sourced from the previous study 1. A total of 7571 L (2,000 gal) of farm well water was evaporated over a single summer, beginning with new paper evaporative cooling pads. At the end of the summer, the four evaporative cooling test stands developed an average of 1,275 g ± 12 g (2.8 ± 0.03 lb) of scale on the 1.86 m² (20 ft²) of evaporative cooling pads (approximately 685 g m⁻²). The heavily scaled pads were sourced from the farm location in southeast Alabama where the well water was collected. The height of these pads was 1.5 m (5ft). The pads were cut down to fit in the test stand. Approximately 15 cm (6 in.) was cut off the top

and the bottom of the pads to remove heavily soiled flutes that develop from dust and debris buildup. A flat jet nozzle (HP1125/HP1125SS, Exair, Cincinnati, OH) attached to an air compressor was used to blow out any loose dirt and debris. The heavily scaled pads were distributed across the four evaporative cooling test stands to achieve a mean scale mass of 20.3 ± 0.07 kg (44.5 ± 0.15 lb) over the 1.86 m^2 (20 ft^2) of pads (approximately 15.8 kg m^{-2}). The approximation of scale is assuming the heavily scaled pads at 1.2 m (4 ft) pads weigh 1814 g (4 lb).

2.3.3 Selection of Descaler Product

To select a commercially available descaler product, a pilot scale study was conducted between four products (chloride product, phosphoric acid product, vinegar, and dishwashing liquid). A heavily scaled paper evaporative cooling pad was cut into five $15 \times 15 \times 30 \text{ cm}$ ($6 \times 6 \times 12 \text{ in.}$) sections. Each section was weighed using a scale, and moisture content was obtained using a moisture probe (RDM3P, Delmhorst Instrument Co., Towaco, NJ) to determine dry weight. A pad section was then placed in each bucket, then each bucket was filled with a different commercially available cleaner mixed per manufacturer recommendations. Each pad was allowed to reside in the cleaner for the manufacturer's recommended time. The pads were then removed, rinsed, and allowed to dry. Once dry, each pad was weighed and adjusted for moisture. The cleaner that removed the most scale from the pad section was selected for the two studies: 30% phosphoric acid.

2.3.4 Evaporative Cooling Test Stands

Four evaporative cooling test stands were used in this project, as described in study 1 (chapter 1) were used in this project. Each evaporative cooling system was labeled (A,B,C,D). All systems consisted of an IBC tank plumbed into a commercially available evaporative cooling system (PACJS2601A1, Portacool, Center, TX). Every test stand was thoroughly cleaned for any

scale build-up, and old IBC tanks were replaced with new tanks at the beginning of this project.

Each 227 L (60 gal) sump tank was filled with water pumped from the IBC tank. A 500 ml water sample (89094-116, VWR International, Radnor, PA) was taken every 76 L (20 gal) while filling the sump tank. Once the sump was full, the commercially available descaler was added to the sump tank at a 1:400 ratio (specified by the manufacturer), and the cleaning mixture was then manually agitated. A 500 ml sample was taken from each sump tank. Each evaporative cooling pad treatment was placed and secured in the evaporative system. The water pump in each test stand was turned on to move the cleaning mixture over the pads for six hours. The sump tank was manually topped off with water from the IBC tank every 38 – 95 L (10-25 gal) of water lost from the cleaner foaming out of the system. At the end of the cleaning session, the sump tank pump was turned off, and a 500 ml sample was taken from the sump tank. All water samples were analyzed by the University of Georgia Extension Soil and Water Testing Center for a W2 water analysis that included a basic mineral water test, anions, soluble salts, and alkalinity.

The evaporative pads were then rinsed using the water in the IBC tank to rinse away any mineral that was loose on the pads. Once the pads were rinsed, the fan on the test stand was turned on at maximum speed to dry the evaporative pads. At the end of the 2 hours, the fans were turned off, and pads were taken out of each test stand and taken into a temperature-controlled building to continue drying for 12 hours. Pad weights and moisture content were taken as previously described. The pads were placed back in the test stands before final pressure measurements were taken. This cleaning process was completed eight times for the minimally scaled and the heavily scaled sets of pads, the first four cleanings used the well water source, and then the last four cleanings were completed using a municipal water source.

A differential pressure gauge (Magnehelic, Dwyer Instruments, INC, Michigan City, IN)

was mounted to the side of the evaporative system. A 6.4 mm (0.25 in.) hose was connected to the pressure gauge on one side, and the other side was placed on a brass port that was drilled through the side of the evaporative system to take pressure readings after every cleaning.

2.4 STATISTICAL ANALYSIS

For each water source study, scale removal and differential pressure were analyzed as two-way ANOVA using the Glimmix procedure in SAS (ver. 9.4, SAS, Cary, NC) with pad scale level and cleaning event as main effects. Cleaning event served as a repeated measure. Means were separated at $P \leq 0.05$ with the pdiff option.

2.5 RESULTS AND DISCUSSION

2.5.1 Study 1: Descaling with Well Water Source

The minimally scaled pads began the study with $1,275 \pm 12.4$ g of scale in each system. Scale removal for the minimally scaled pads using the farm well water source ranged from a high of 335 g removed during the first cleaning to a low of adding 17 g of scale during cleaning 2 (fig. 2). The overall mean scale removal was 130 ± 77 g per system per cleaning. After the four cleaning events, a total of 521 g (-41%) of scale was removed from the system.

The heavily scaled pads began the study with sixteen times the scale of minimal pads, 20.3 ± 0.07 kg (44.7 lbs). Scale removal for the heavily scaled pads using the farm well water source ranged from a high of 240 g removed during the fourth cleaning to a low removal of 78 g of scale during cleaning 1 (fig. 3). The overall mean scale removal was 156 ± 44 g per system per cleaning. After the four cleaning events, a total of 624 g (-3%) of scale was removed from the system.

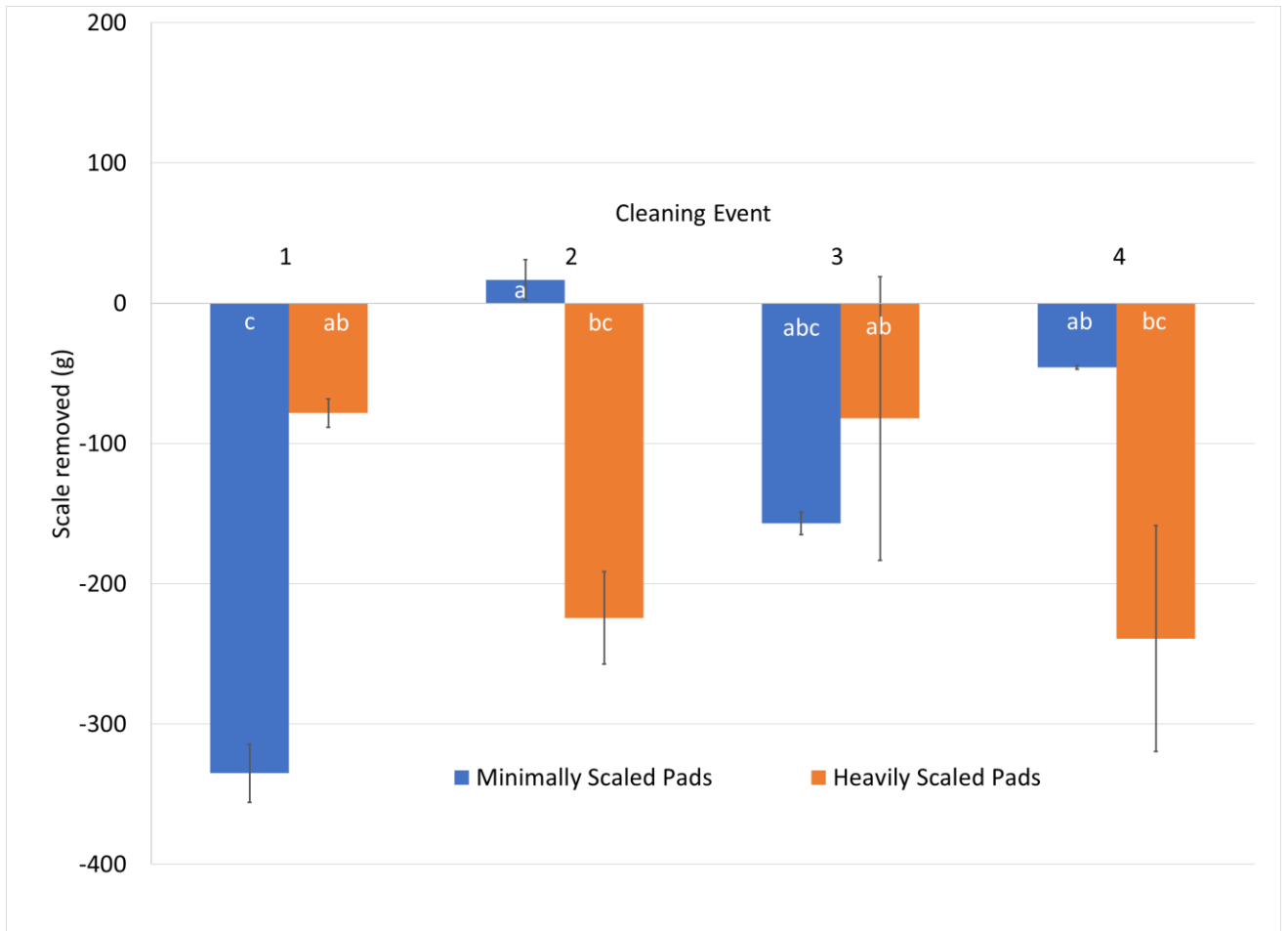


Figure 6: Scale (g) removed from each pad treatment over four cleaning events using well water.

Pressure was taken at the beginning of the study, and after each cleaning, there was a significant difference ($P = 0.0119$) between the minimally scaled pads and the heavily scaled pads. There was not a significant difference between the cleaning events for either pad treatment. Differential pressures were higher in the heavily scaled pads than the minimally scaled pads.

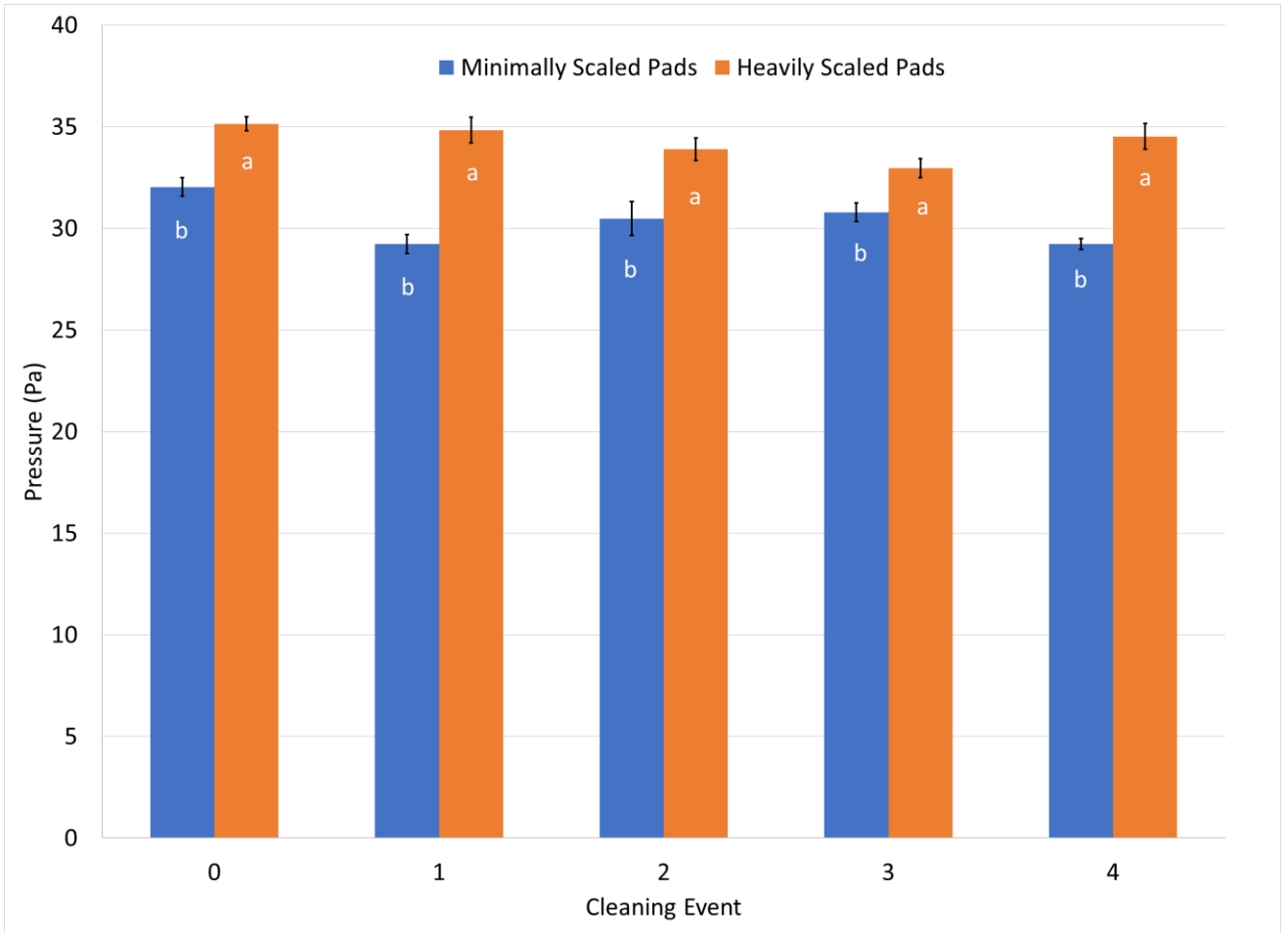


Figure 7: Differential pressure measured across the pads for each pad treatment at the beginning of the study (0) and after each cleaning using the well water source.

2.5.2 Study 2: Descaling with Municipal Water Source

The minimally scaled pads began the second study with 690 ± 26 g of scale in each system. Scale removal for the minimally scaled pads using the municipal source ranged from a high of 84 g removed during the second cleaning to a low of adding 51 g of scale during cleaning 1 (fig. 4). The overall mean scale removal was 41 ± 31 g per system per cleaning. After the four cleaning events, a total of 166 g (-24%) of scale was removed from the system.

The heavily scaled pads began the study with roughly 19.6 ± 0.04 kg of scale in each system. Scale removal for the heavily scaled pads using the municipal water source ranged from a high of 257 g removed during the fourth cleaning to a low of adding 21 g gained of scale during cleaning 2 (fig. 5). The overall mean scale removal was 99 ± 63 g per system per cleaning. After the four cleaning events, a total of 396 g (-2%) of scale was removed from the system.

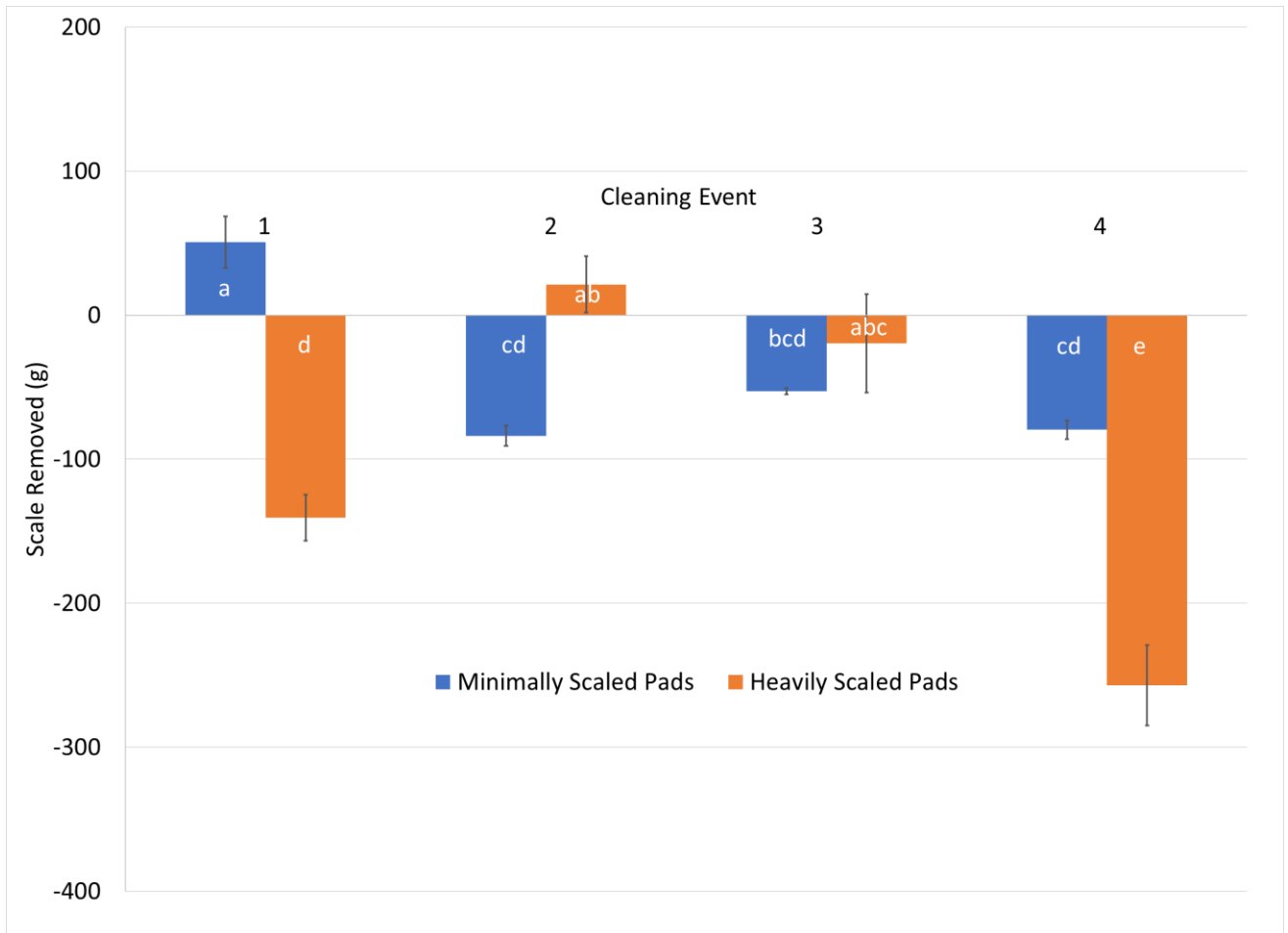


Figure 8: Scale (g) removed from each pad treatment over four cleaning events using the municipal source.

The differential pressure was taken at the beginning of the study, and after each cleaning, there was a significant difference ($P=0.0017$) between the minimally scaled pads and the heavily scaled pads. There was not a significant difference between the cleaning events for either pad treatment. Differential pressures were higher in the heavily scaled pads than the minimally scaled pads.

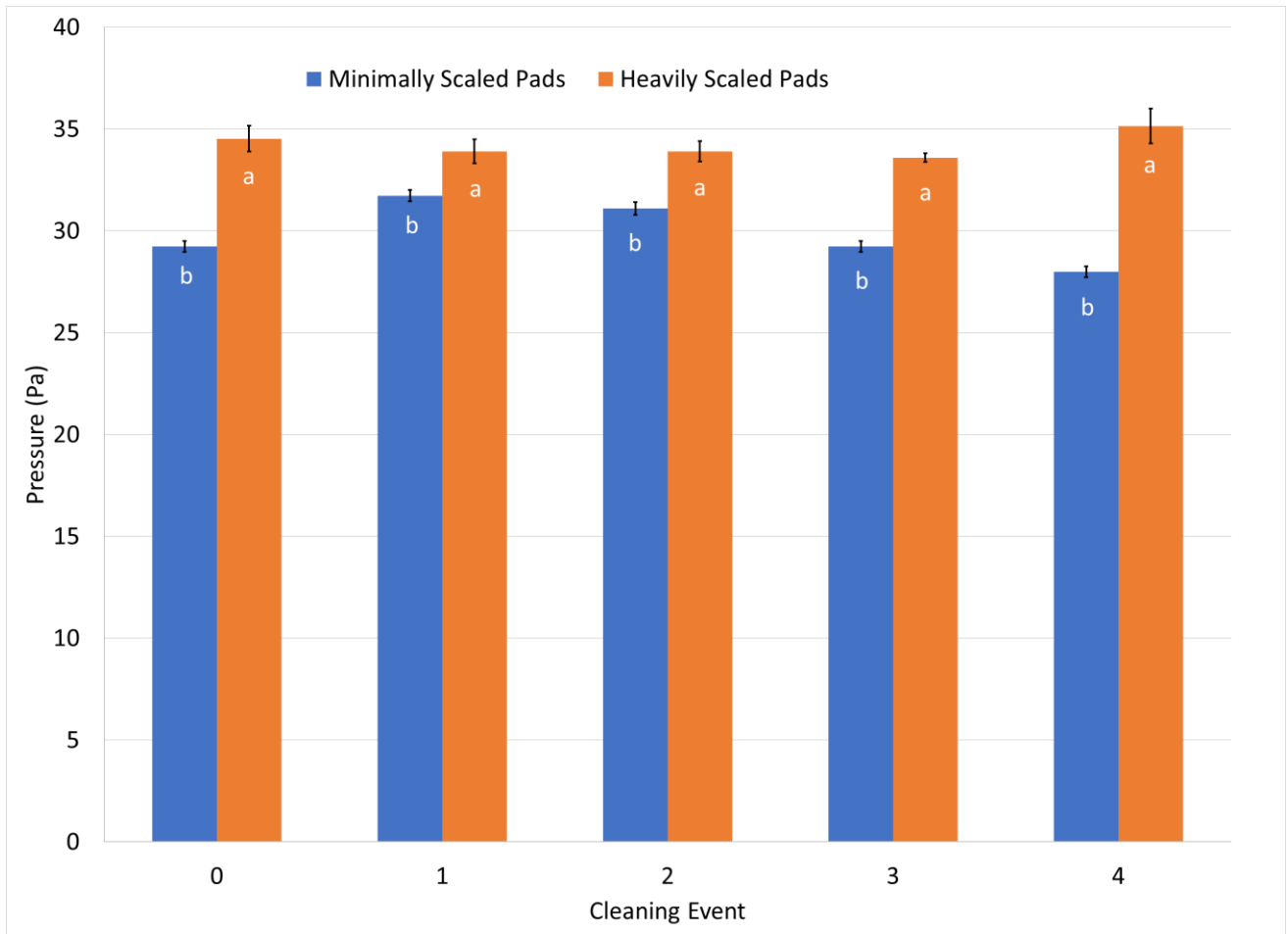


Figure 9: Differential pressure measured across the pads for each pad treatment at the beginning of the study (0) and after each cleaning using the municipal water source.

If all four cleaning events from both well water and municipal water were combined for the minimally scaled pads, the overall scale removal would be 687 g (54% removal) using the commercially available descaler. These cleaning events included the complete flushing of the system sump and beginning with clean water. Most producers don't attempt to descale until there is a reduction in airflow in the broiler houses. Producers expect to remove enough of the scale in a single cleaning event for the pads to be like new. This project illustrates that it is important for producers to clean more frequently and remove the scale as it forms. According to Snoeyink & Jenkins (1980) it is harder to remove scale as it "ripens" and becomes a more stable structure. As the scaled structure obtains more precipitation, it usually becomes more stable when the

evaporative pads are not cleaned for multiple flocks. Eight cleaning events on new pads would be beneficial to the longevity of the pads and to maintaining the ventilation system performance.

If all four cleaning events from both well water and municipal water were combined for the heavily scaled pads, the overall scale removal would be 1020 g (5% removal) using the commercially available descaler. These cleaning events included the complete flushing of the system sump and beginning with clean water. Once the scale has hardened, it is hard for the commercially available descaler to penetrate and dissolve the stable scale. We also witnessed that a proportion of the scale removal weight was chunks of debris and paper that would dislodge during the cleaning process. Performing eight cleaning events on heavily scaled pads would be a waste of time, effort, and cost of the descaler.

2.6 CONCLUSIONS

- Using the farm well water source, a total of 521 g and 624 g were removed for minimally scaled and heavily scaled pads, respectively.
- Using the municipal water source, a total of 166 g and 396 g were removed for minimally scaled and heavily scaled pads, respectively.
- Over eight cleaning events, a total of 687 g and 1020 g were removed for minimally scaled and heavily scaled pads, respectively.
- It is important for producers to proactively manage scale formation on evaporative cooling pads through more frequent cleaning events beginning when pads are new. Waiting until pads are heavily scaled before addressing the scale build-up creates a scenario that becomes difficult to improve.

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