Ozone For Cooling Tower Systems - An Update And Lessons Learned At The Kennedy Space Center

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SUMMARY: The operational experience and performance of the successful use of ozone as a stand-alone cooling water treatment method are discussed. Several guidelines for design parameters and operational controls are presented. From a wide field of application experience, the author offers several lessons-learned relating to generator types, capacity, dosage, corrosion, and microbiological control. From the evolution of early struggles and disenchantment, specific information on what should be done is provided as well as what must be avoided. Unlike conventional chemical programs, ozone treatment based upon applied rates and dosages remain controversial, but case studies continue to explore and validate this emerging technology.

INTRODUCTION

Prior to 1990, cooling towers at Kennedy Space Center (KSC) had been maintained using conventional chemical treatment consisting of a scale and corrosion inhibitor (two phase), and two alternating biocides to control bacteriological growth. Tower chemistry was controlled through discharge by blowdown to area surface waters. Stricter environmental regulations began to impact cooling tower operations. State regulatory code establishes the criteria for surface water quality, and therefore dictates the standards by which any waters discharged to surface water must comply. Due to chemical additives and operating water chemistry, the blowdown discharge could not meet the environmental regulatory criteria.

In 1990, NASA and the Base Operations Contractor, formerly EG&G Florida Inc., began to explore numerous avenues that would yield cooling tower environmental compliance. One of these considerations had been studied at KSC since as early as 1984, and at the NASA Jet Propulsion Laboratory prior to that. This technology was the application of ozone to cooling water treatment, which will be expanded upon from both a historical and technical viewpoint in this paper.

BACKGROUND

In 1992, Kennedy Space Center (KSC) modified six comfort-cooling towers from conventional chemical feed water treatment systems to ozone treatment systems. All systems were intended to operate at zero blowdown thereby significantly increasing the cycles of concentration of these towers. The feasibility of this practice was re-assessed as detrimental to operation and steps were taken to initiate limited blowdown to the sanitary sewer. Even the short-term period of zero blowdown culminated in severe scaling of condenser tubes, tube-heets, and housings. With environmental compliance being met and gaining concurrence from the appropriate organizations a realistic program approach began to emerge.

In reality, the ozone treatment program remained problematic due to poor equipment reliability and the undersizing of ozone generator capacity. These initial experiences, coupled with the changing climate of facility expansion/construction and chiller plant centralization, formed the evolutionary pathway for KSC in the application of ozone water treatment. Despite the treatment difficulties, water treatment personnel at KSC and supporting industrial resources (system and equipment supplier), remained confident in the technology application and the positive attributes that ozone demonstrated. With pensive feeling mounting within NASA, two independent A&E studies were conducted to investigate the most feasible treatment method for the cooling towers.

Each engineering study recommended ozone treatment for the KSC cooling towers and the project was subsequently awarded to the same A&E firm for the design phase. However, it became apparent that the A&E authorized by a NASA contract, held a widely diverging engineering approach and philosophy for ozone treatment from those understood by KSC personnel and their industry interface (the KSC alliance).

KSC INSTALLATIONS

VEHICLE ASSEMBLY BUILDING (VAB) - The Launch Complex 39 Area central plant cooling tower, the largest at the space center, proved to be the most challenging system on ozone treatment. The Utility Annex (UA) provides chilled water used to maintain temperature and humidity control within various launch-related facilities during Space Shuttle processing. The Utility Annex system is comprised of four 2500 ton and one 1180 ton centrifugal chillers. This four cell ceramic filled concrete cooling tower can provide 10,000 tons of air conditioning cooling capacity. Ozone treatment was initiated during February 1994. Since 1996, this chiller plant has been expanded to serve as campus style cooling for most facilities within the launch area.

INDUSTRIAL AREA CHILLER PLANT (IACP) - The cooling requirements for major facilities within the KSC Industrial Area are met with the recent addition of a central chiller plant co-constructed with the Space Station Processing Facility (SSPF). Known as the Industrial Area Chiller Plant (IACP), the heat rejection system is unique in that two cooling towers are interconnected with a 36-inch line and receive makeup water in the west tower only. The newer east-cooling tower has a capacity of 8300 tons, while the older tower rated at 3500 tons is intended to supplement the IACP during outages. Each cooling tower is equipped with a separate ozone system and is ozone fed individually. The cooling water system has been treated with ozone since 1988 with good equipment reliability and satisfactory treatment results.

This discussion will primarily focus on the VAB Utility Annex cooling tower since this facility experienced several iterations with generator equipment until the transition into a designed or engineered ozone system for the installation and is a conventional single 4-cell tower. In addition, at 10,000 tons capacity, this installation exists as one of the largest of most typical treatment applications.

HISTORY

The various stages of evolution for the ozone treatment systems at the VAB Utility Annex are presented below in Table 1 to illustrate the progression from marginal to successful treatment based upon equipment, capacity and reliability factors.

Table 1- Ozone History

History of Ozone Treatment System at VAB Cooling Tower				
Stage	**Period**	**Equipment Type**	**Installed Capacity**	**Ozone Yield, %**
Phase I	94 – 96	1st Generation, air-fed/air-cooled (AC)	10.5 lbs/day; 2 gr/hr/100 tons	0.75 - 1.5
Phase II	96 – 97	1st Generation, air-fed/air-cooled (AC)	16 lbs/day; 3 gr/hr/100 tons	0.75 - 1.5
Phase III	97 – 99	2nd Generation, air-fed/ air-cooled (AC)	17.5 lbs/day; 3.8 gr/hr/100 tons	1 - 2
Phase IV	99 - present	2nd Generation, oxygen-fed/water-cooled	130 lbs/day; 20 gr/hr/100 tons	4.5 - 6.6

DESIGN REQUIREMENTS

OZONE REQUIREMENTS - A leading question asked by users and practitioners alike is, “How much ozone is required?” This issue has been a major focus at KSC since the installed systems have been acknowledged to be under-capacity since their inception in 1992. A system sizing rule-of-thumb held by some applications providers is 3-5 grams/hr ozone generator capacity per 100 tons cooling. The KSC alliance held a more realistic confidence in an ozone capacity of 5–6 gr/hr/100 tons as a target for the VAB cooling tower.

However, the author has witnessed a separate KSC installation at a nearby aerospace contractor facility (Booster Assembly Facility) experiencing apparent successful treatment at an ozone capacity of 2 gr/hr/100 tons on an 1800 ton system (3 X 600 ton). This discrepancy would not appear to be unusual, except for the fact that the VAB and booster facility installations are less than two miles away and share a common makeup water source.

Under a NASA contract, an independent A&E design planned to install 130-lbs/day ozone capacity at the Utility Annex cooling tower referenced in this analysis. This translates to approximately 20 gr/hr/100 tons. The following analysis and discussion will attempt to provide some insight into these disparities regarding dosage and capacity.

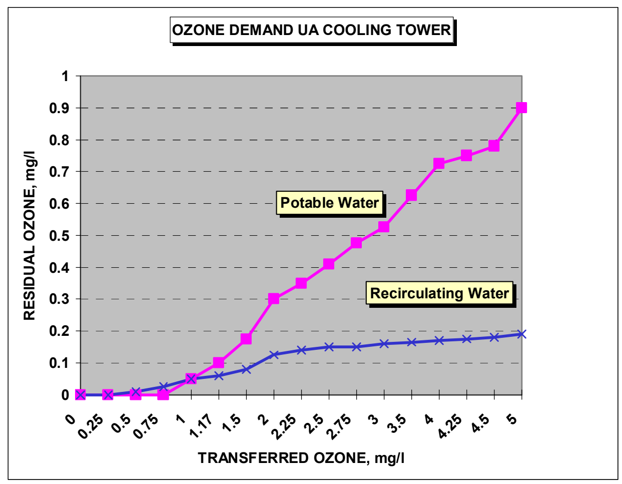
<u>Ozone Demand</u> - Ozone demand tests, not necessarily required for design capacity, were conducted at KSC in concert with a water reuse study considering the use of domestic wastewater secondary effluent as makeup to the cooling towers. The physical and chemical conditions are indicated in Table 2, while the following system data and demand curve expressed by Figure 1 form the basis to determine the amount of ozone capacity required assuming an operating target of +550 mV ORP (0.1 mg/l O3 residual) at the UA cooling tower:

Basin (Sump) Volume	204,000 gal
System Volume	240,000 gal
Makeup Water	150,000 gpd
Recirculation Flow	30,000 gpm
Ozone Sidestream Flow	2,000 gpm
Ozone Transfer Efficiency	90%
Basin Hydraulic Detention Time (Theoretical)	8 minutes
Average Detention Time (Assume 50% of Theoretical)	4 minutes

Table 2 – VAB CT Data

VAB Cooling Tower Cell Parameters		
Parameter	**Potable Makeup Water**	**Cooling Tower Recycle**
Flow (gpm)	15	7,500/cell
Temperature (°C)	27	27.5
Conductivity (μmhos/cm)	470	3650
PH	8.76	8.87
COD (mg/l)	9	80
TOC (mg/l)	4	33.7

Figure 1. Ozone Demand at VAB Utility Annex CT



The amount of ozone required to satisfy the demand exerted by the potable water makeup and the recirculating water to produce an ozone residual of 0.1 mg/l is given below in Table 3.

Table 3 – Ozone Demand

Ozone Demand			
Source	**Applied Ozone Dose (mg/l)**	**Transferred Ozone (mg/l) [a]**	**Ozone Feed Rate (lb/day)**
Potable Water	1.3	1.17	1.63
Recirculation	1.78	1.6	42.72[b]

NOTES: a. Based on 90% mass transfer efficiency
b. Flow basis is 2,000-gpm ozone injection sidestream (4-cells)

It is interesting to note that the recirculating water of the operating cooling tower poses an ozone demand 37% greater than that of the potable water makeup, indicative of the loading dynamics. Also note that the chemical oxygen demand (COD) and total organic carbon (TOC) levels within the tower are concentrated eight-fold as corresponding with cycles. Based on the above information the projected ozone capacity required is approximately 43 lbs/day based on tower basin and an allowance for makeup flow demand, which is cyclic would total 44 lbs/day. This rate corresponds to approximately 8.3 g/hr/100 tons.

Although the above ozone demand studies were performed independently and separately from the new upgrade project, a designer would tend to base ozone capacity requirements upon the results or focus toward a 5-10gr/hr/100 tons. However, other factors must be considered in predicting ozone capacity requirements due to the influence of: dynamics of a flowing system versus ozone demand test under static conditions, the output yield (O_3 wt %) of the ozone generator, and mass transfer efficiency of a two-phase mixing method. Another factor influencing ozone demand may be post-reactivity and scavenging effects of secondary products within a grab sample. The KSC alliance adhered to the 3-6 gr/hr/100 tons for the new design while not discouraging potential benefits of ozone demand tests.

Ozone Mixing - The critical design parameter for ozone gas-liquid mixing becomes apparent for non-engineered systems manifested as cooling tower basin off-gassing problems and poor ozone residuals. Progressive work done by others with regard to two-phase mixing principles applied to maximize mass transfer efficiency has inspired the KSC alliance to modify all ozone systems accordingly.

Based upon bubble froth pipe flow mixing, the stream pattern represents bubbles of gas dispersed throughout the liquid occurring for liquid velocities approximately at 5-15 ft/sec and for gas velocities at 1-10 ft/second.[1] For existing systems, the enhancement is readily achieved by modifying the diameter and/or length of the ozone distribution piping from the eductor to basin. Given the pump flow rate and subsequently sizing the diameter for a turbulent region at approximately 10 ft/sec, the expression L/D = 300 should be applied to the ozone distribution piping to each cell. The method essentially employs the mechanisms of a pipe reactor and the results were beneficially apparent at each of the KSC cooling towers with a mass transfer efficiency approaching 90%.

The KSC alliance vigorously urged the NASA/A&E project team to utilize the eductor/engineered pipe system in lieu of a proposed gas/liquid contact tank as a mixing method for the new design.

Generator Equipment - First generation air-cooled ozone generators proved to be unreliable with regard to electrode assembly dielectric failures. The newer manufactured air-cooled units showed an improved reliability, but unexpected failures required periodic maintenance for dielectric replacement. A hybrid electrode retrofitted into one air-cooled generator performed well for two years. Concurrent experience with water-cooled machines indicated continuing reliability resulting as uninterrupted treatment for five years or more with only periodic downtime for annual or preventative maintenance.

Another critical attribute for ozone generator performance is the higher output yield resulting from an oxygen source rather than air. This feature becomes significant for treatment efficiency when viewing the relationship that solubility of ozone increases with higher gas concentrations. The KSC experience with air-fed ozone generators (air- and water- cooled) yielded 0.75-2.0% wt. ozone output. These output measurements indicated an ozone production of 66-74% nameplate rating.

The new ozone system would be specified as water-cooled by chilled water at 39^o F attemperated to 60^o F. The ozone generators are oxygen-fed by two pressure-swing adsorption air separation units which invariably measure >95% oxygen as supply and an output yield at 6-14% ozone.

TREATMENT

NEW INSTALLATION - The newly designed and constructed ozone treatment system at the VAB Utility Annex cooling tower was inaugurated into service in April 2000. The previous ozone treatment since 1994 was marginal at best and was supplemented by periodic bromine additions during the high climatic seasons of the Florida summer. The makeup water was a blended stream of approximately 60/40 potable and softened water.

Following a 90-day ozone treatment hiatus during construction, the 10,000-ton tower transitioned into ozone kinetics after 12-16 hours following start-up. This point was noted by basin water characteristics in which a milky haze, punctuated with pinpoint floc faded into clarity. The ORP set-point was initially 700-800 mv during start-up but was decreased in accordance with corrosion rates. A two-week testing and validation period prior to turnover was conducted performing water chemistry analysis including microbiological. The microbiological results showed no colony growth on dip-slides during the period at 700-800 mv.

Treatment Description - The five (5) 26-lbs/day water-cooled, oxygen-fed ozone generators were initially set in the automatic mode to maintain a set-point at 550 mv ORP. Upon attaining equilibrium, the generators modulated to an output at 20% capacity and continue at this loading to present time. Thus, the actual threshold treatment requirement for this tower is 26 lbs/day or 492 gr/hr representing an applied dosage of approximately 5 gr/hr/100 ton. It should also be noted that this dosage occurs at an average tower loading capacity of 50-55% over the year.

Engineering Data - The following engineering values in Table 4 were derived as the designer is aided by use spreadsheet calculations, ensuring the placement of flow conditions into the bubble froth region of the two-phase flow diagram.[2,3] Note that the parameters indicated correspond to each tower cell.

Table 4 – Engineering Data

Ozone Supply Piping to Distribution - VAB Cooling Tower	
Parameter	**Value**
Water Flow Rate, gpm	1050
Gas Flow Rate, scfh	200
Pipe Diameter, ID in. 6” sch 80	5.761
Ozone Conc. In Feed, % by wt.	6.0
Min. Pipe Length, L/D=300, ft	144
Velocity, ft/sec	13.2
Reynolds Number	575,475
Contact Time, sec	10.9
ΔP per 100 ft, psi	4
Delivered Ozone, mg/L	1.7

WATER CHEMISTRY AND RESULTS

SCALING - Scaling of the condenser tubes for the 2500-ton machines have remained a high concern at KSC in the aftermath of the early ozone program with marginal capacity and mandated practice of zero blowdown. Also, in accordance with energy conservation goals for federal facilities, KSC actively implements and monitors energy management programs.

Typically, the cooling towers are cycled up to a “non-corrosive” state while allowances for further cycles of concentration are operated based on predicted scaling indices. The indices used to forecast scale and corrosion in water are all connected to the alkalinity and calcium content. At a saturation condition based on temperature, precipitation of calcium carbonate, a tenacious, insulating material can be predicted. However, none of the indices (Langelier, Ryznar, and Puckorius) factor in biological activity.

Predicting scale formation in a cooling tower by use of an index without factoring in biological activity is widely acceptable for conventional treatment but may be a questionable approach using ozone. The Practical Ozone Scaling Index4 (POSI) is a useful development for the ozone case. The index provides greatly improved correlation with real-world-derived scaling tendencies in ozonated cooling systems compared to traditional chemical programs using LSI, RSI, and PSI type indices. This is solely due to the ability of ozone to almost completely disinfect the cooling water loop.

The Practical Ozone Scaling Index predicts a limit of 18 cycles of concentration for the VAB cooling tower. This agrees well with a NASA laboratory study for the solubility limit of calcium sulfate within the actual cooling water. Calcium sulfate is the primary focus since the mineral was the major component identified within the scale deposits of 1994. A modified LSI for use with ozone allowing a +2.0 target value predicts 10-12 cycles.

Silica is typically high in Florida groundwater (source of city water is deepwell) and should be monitored due to the heat transfer and maintenance impacts associated with silica scale. The control level for silica, generally published at 140-mg/l limit, should be evaluated for each specific case since silica chemistry is very complex and is dependent upon other water constituents[5]. A cooling tower operating criteria regarding silica has been adopted for KSC:

Magnesium as CaCO3 x Silica as SiO2 < 30,000 Equation (1)

Again, the relationship described by Equation (1) illustrates the positive attributes of softening with the attendant magnesium reduction. Polyphosphate is added to the potable water system at a re-pump station upon entry to KSC to control copper, iron, and lead is the aged drinking water lines. The phosphate content is generally a concern in cooling water systems due to the tenacious nature of calcium phosphate scale and the presence of the phosphate ion has the potential to nucleate or "seed" other mineral crystals. For this reason, the phosphate addition is moderated at lower levels to generally produce 0.50 mg/l ortho-phosphate residuals.

Condenser tube deposition is monitored by a visual inspection upon waterbox removal at a period twice per year. The inspections continue to indicate that generally the tubes are clean, deposit-free with the exception of moderate deposition (dusting and mottled light scale) at the tubes positioned at the bottom of tube bundle. This condition may be attributed to draining and dry-out aspects of the condenser or localized hot spot areas.

Scaling concerns prevail though since the condensers were re-tubed by year 2000 with the enhanced tube type with an internal rifling pattern and pose a challenge to the water treatment program. The towers are operated at 10-12 cycles, with blowdown occurring at conductivities of 6000 micromhos with softened makeup blend, 5000 micromhos with potable water makeup.

CORROSION - Generally, high corrosion rates are not evident with the total alkalinity maintained above 240 mg/L. However, this threshold appears to be readily compromised with higher magnitudes of ORP—above 550 mv as indicated by Figure 3. A minor risk element exists due to the tendency of the control ORP probes to foul prompting frequent maintenance but without receiving full-time attention during the automatic mode of operation. Figure 2 depicting the relationship of ORP value to dissolved ozone was developed by laboratory testing during the water reuse study.

Figure 2 – ORP Vs. Ozone

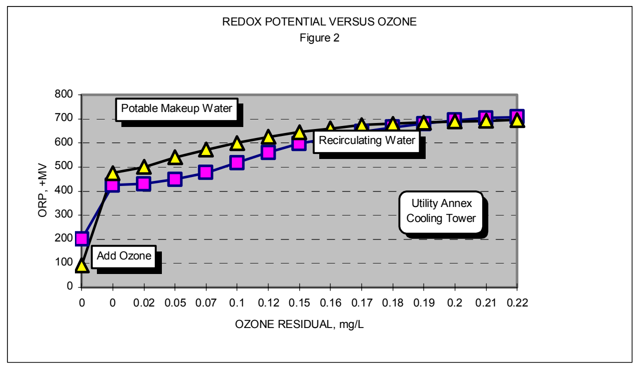
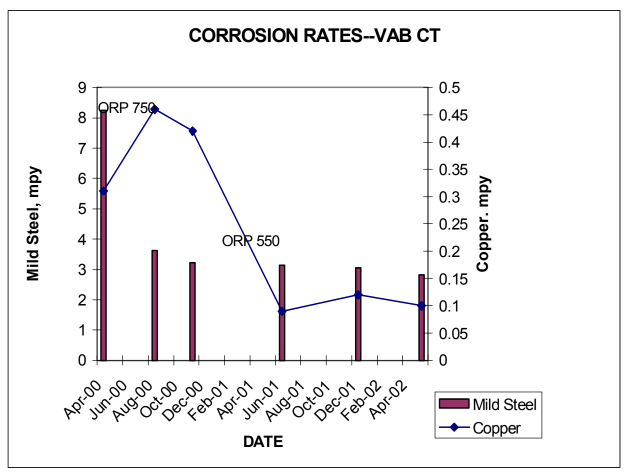


Figure 3 – Corrosion Rates – VAB CT



WATER CHEMISTRY PARAMETERS - Although partial makeup water softening was employed until 2001, the practice was abandoned due to excessive maintenance requirements as the units were degraded by exposure to outdoor conditions. Conditioning a portion of makeup has previously allowed higher cycles of concentration during the earlier programs of marginal ozone capacity, and softening may be re-evaluated to provide greater deposit control for the enhanced condenser tubes. A sidestream sand media filter was installed in early 2000 as an adjunct to the ozone program. The 2-micron rated filter system flows at 420 gpm (1.4% recirculating volume) and produces an incredible clarity of the basin in conjunction with the ozone treatment. The backwash volume of 1800 gpd from the basin also serves as a daily blowdown component. Quantitative benefits attributed to sidestream filtration are the reduction of solids loading in the cooling water by 80% and subsequently reduces maintenance resources and frequencies of cooling tower basin cleaning. Overall, the sidestream filter compliments the efficiency and demonstrated success of the ozone treatment regimen at the VAB cooling tower. The actual ranges of water chemistry parameters are presented in Table 5.

Table 5 – Water Analyses

Water Chemistry Control		
Parameter	**Makeup Water City of Cocoa**	**Cooling Tower**
Calcium as Ca^{+2}, mg/l	30 - 40	240 - 355
Magnesium as Mg^{+2}, mg/l	15 - 21	130 - 240
Total Hardness, $CaCO_3$ mg/l	110 - 140	900 - 1300
P-Alkalinity, $CaCO_3$ mg/l	<1 - 4	35 - 63
M-Alkalinity, $CaCO_3$ mg/	32 - 46	236 - 335
Chloride, Cl^-, mg/l	60 - 110	800 - 1200
Sulfate, SO_4^-, mg/l	100 - 110	1000 - 1500
Silica, SiO_2, mg/l	16 - 22	90 - 140
Phosphate, o-PO_4^{-2}, mg/l	0.3 - 0.6	<5
Total Dissolved Solids, mg/l	360 - 400	2600 - 3600
Total Iron, mg/l	0.11 – 1.2	0.01
Total Copper, mg/l	0.02	0.01
Total Organic Carbon, mg/l	3 - 5	<1
pH	8.6	8.8 – 9.0
LSI	-	+2.0 – 2.5
Cycles	-	9 - 12
Total Suspended Solids, mg/l	-	<1
Turbidity		<0.1

BLOWDOWN – The total blowdown volume is approximately 9,000 – 12,000 gallons per day which is discharged to the domestic wastewater treatment plant. Although, the blowdown rate presents neither a hydraulic nor a chemical impact to the wastewater treatment plant, earlier concerns focused on specific parameter limits for the plant final effluent to surface waters. Similarly, these same parameter limits precluded the blowdown as a suitable candidate for irrigation or land application due to exceedances for sodium and fluoride maximum contaminant levels (MCL) of 160 and 4 mg/l respectively. In reality, the blowdown to the wastewater plant has a beneficial aspect where the alkalinity background buffers the inherent pH decline normally associated with the activated sludge process. Therefore, manual pH adjustments by bagged soda ash handling is no longer required.

The ozone treatment program at KSC's largest cooling tower has been successful due to extensive background experience of marginal or near-failure treatment regimes which has enabled an acquired understanding of the technology. The lessons-learned have provided critical input into a new design that maximizes transferred ozone to the water phase, selected reliable generators and ancillaries, and also benefited from the current technology state. The treatment effectiveness is noted by the periodic condenser inspections indicating deposit-free surfaces and no evidence of unacceptable corrosion. The program is challenged by the recent replacement of condenser tubes with the enhanced, rifle bore type, which recently indicated deposition within the spiral groove.

Areas of future study would include an evaluation for implementing the return of partial makeup water softening to mitigate water chemistry excursions in the municipal potable water and permit higher cycles of concentration and thereby enhance water conservation. An investigation into process control upgrades such as more reliable, minimal maintenance ORP probes or the use of dissolved ozone monitoring/control would be beneficial as both an equipment and operational improvement. A more frequent interval for corrosion coupon cycles, microbiological monitoring, and periodic testing for Legionella would also be candidates for future recommendations to operations personnel.

CONCLUSION

The use of ozone at Kennedy Space Center entails a varied history, ranging from marginally effective to a resounding success. As a guideline for the designer, the KSC experience determined that an installed ozone capacity of 3 – 6 gr/hr/100 tons should be sufficient treatment and redundancy for a generator should be considered. Ozone gas/liquid mixing is accomplished effectively with an eductor/engineered piping system (velocity @10 – 15 ft/sec; L/D = 300) with mass transfer efficiencies of 90%. Cooling tower basin ozone levels at 0.07 – 0.10 mg/l provide effective treatment with minimal corrosion, the residual concentrations corresponding with approximately 500-550 mv ORP. The treatment regime consisting of stand-alone ozone complimented by sidestream filtration has produced good cooling water treatment results in the control of scaling, corrosion, and microbiological effects.

Federal facilities, including Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS) continually strive to achieve federally mandated goals required by the Federal Energy Act, but also exhibit good corporate citizenship by embracing water conservation technologies within their locale. Operating at the higher cycles of concentration afforded by ozone, the total difference in blowdown volumes experienced previously compared to current practice has yielded water conservation of 32 million gallons per year and a annual water savings of $48,000. In addition, with previous conventional chemical treatment costs at approximately $6.50/ton/year, or $65,000/year, the total operation and maintenance costs for ozone approach one-third this expenditure. Finally, as KSC has achieved a successful ozone treatment program the realization that a concomitant response towards the proper management of water resources is both an economical and environmental benefit.

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