Cyanuric Acid in Commercial Swimming Pools and its Effects on Chlorine's "Staying Power" And Oxidation Reduction Potentials

By

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Abstract

Cyanuric acid levels in commercial swimming pools has been a controversial topic in the swimming pool industry in the past few years. This chemical is known for its stabilizing abilities by protecting chlorine from the ultraviolet rays of the sun which cause photolysis. Cyanuric acid has received recognition for this ability, but has also received blame for over stabilization which reduces the effectiveness of sanitization and oxidation reduction potential (ORP) of chlorine. This loss in effectiveness could possibly result in recreational water illnesses arising due to water quality standards being compromised.

Local and state regulations can make it unclear on what parameters cyanuric acid levels should be in commercial swimming pools due to its inconsistencies across the United States. These variances are wide and could possibly lead to confusion amongst pool professionals to exactly where they should be when applying this chemical. In this project a look at the “staying power” of chlorine and its oxidation reduction potential at various levels of cyanuric acid will hopefully develop an understanding on where the ideal range of this chemical should be kept. This along with surveys from North Carolina professional pool companies and an interview with a local official who oversees commercial pool inspections in Wake County will develop a foundation on the perception of how pool professionals view this chemical and its capabilities along with testing for its levels.

An overall ideal range on cyanuric acid levels for swimming pools that require stabilized chlorine will be reached through the information gathered on this project. This will help the pool professional understand its use and keep higher water quality standards in commercial swimming pools.

Biography

Aaron Askins began his career in the swimming pool industry during his sophomore year at Indiana University while in pursuit of his Bachelor's Degree in Business Administration. Upon completion of his degree, he continued to stay within the trade and has worked in many facets of the industry including service, construction, and distribution. During this time, he has not only helped in the construction of hundreds of pools, but has also spent an abundant amount of time in chemistry and technical training. In the past he has felt that the industry has always been somewhat antiquated and has lagged in technological development, as well as, a lack of growth in professional individuals to help promote advancement in the industry. He would like to continue to see an influx of educated individuals enter the industry, as well as, help the people that are currently within the trade achieve the necessary training that will benefit them in the industry.

Aaron's aspiration to have a career in the environmental field has pushed him to look at issues in the swimming pool industry that have impacted the environment and the people that are within it. He entered the Masters of Environmental Assessment Program at North Carolina State University due to the desire to be within this field, as well as, his passion for studying science and natural resources. Aaron hopes to further develop himself within the environmental arena so that he can cultivate a career that will ultimately help individuals and businesses improve themselves so that today's environmental issues will diminish.

Acknowledgements

I would like to thank all the professional pool companies who took time to speak with me on the questions I had about cyanuric acid levels in commercial swimming pools. This allowed me to form a foundation on what the first-hand perception was of this chemical within the North Carolina swimming pool industry. I would also like to thank the Section Chief of the Wake County Plan Review and Sanitation Program, Terry Chappell, for his time in providing what is expected by local officials when regulating and maintaining commercial swimming pools. His information on regulations and testing provided me with what the pool professional faces while maintaining their commercial swimming pools.

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1 Introduction

Cyanuric acid ($C_3H_3N_3O_3$) in chlorinated swimming pools reduces the rate of decomposition of free available chlorine by ultraviolet rays in sunlight. This odorless white granular substance, which also goes by the names of stabilizer or conditioner, has been used in public and private swimming pools since 1958 to increase the stability of chlorine (O'Connell, 2003). The desire to have stabilized chlorine is derived from a need to properly sanitize water that will be used by humans for recreational use. Since many pools rely on chlorine compounds to kill bacteria and viruses that can be introduced to a swimming pool, it is important that free chlorine levels are not compromised. A compromised chlorine level could lead to recreational water illnesses that could be resultant from viruses, germs, and bacteria that include culprits such as cryptosporidium, giardia, legionella, and MRSA.

The swimming pool industry is an expansive industry that involves over 10.5 million swimming pools in the United States (APSP, 2013). According to the Center for Disease Control and Prevention (CDC) approximately 301 million swimming visits were made to swimming pools by persons over the age of six in 2009 making it the fourth most popular recreational activity in the United States (Centers for Disease Control and Prevention, 2013). Going deeper into this data, thirty-six percent of children the age of 7-17 years and fifteen percent of adults swim at least six times a year. For the ages of 7-17 years, this means swimming is the most popular recreational activity in the United States. Due to the incredible vastness of the people involved with this recreational activity, regulations are put forth for the commercial part of the industry to control how these bodies of water are chemically maintained. Some research shows that these regulations are inconsistent and can vary state to state, county to county, and even sometimes inspector to inspector. The question could be asked if this inconsistency within regulations could create confusion amongst pool professionals that may lead to poorly maintained pools and therefore an increased risk of recreational water illnesses.

The CDC stated that in 2008 almost 1 in 8 (12% or 13,532 of 111,487) routine pool inspections conducted identified serious violations that threatened public health and safety and resulted in immediate closure. Also the CDC specified that more than 1 in 10 (10.7% or 12,917 of 120,975) routine pool inspections recognized pool disinfectant level violations (Centers for Disease Control and Prevention, 2013). The CDC recommends chlorine be continuously at 1-3 parts per million. These type of violations in 2007-2008 resulted in nearly 14,000 cases of recreational water illnesses being reported to the CDC. *Cryptosporidium* is a highly chlorine resistant parasite that infects the small intestine (Kraft, 2010) and was a major culprit for these illnesses.

Chlorine, in one form or another, is the most used barrier to the spread of germs in the water that people swim. Swimming pool chlorines come in six forms and can be classified as an unstabilized or stabilized form. Unstabilized chlorines include chlorine gas (Cl_2), sodium hypochlorite (NaOCl), calcium hypochlorite ($Ca(OCl)_2$), and lithium hypochlorite (LiOCl). An additional alternative to unstabilized chlorine use are salt systems that use electrolysis to produce a sodium chloride solution. Stabilized chlorines, which contain cyanuric acid and are also known as chlorinated isocyanurates, include Trichloro-s-triazinetrione (Trichlor) and Sodium Dichloro-s-triazinetrion (Dichlor). Dichlor is usually marketed for the residential swimming pool market whereas Trichlor is often used for small commercial pools, such as those at hotels and motels (Lincoln, 2008). These different types of chlorines can also vary by ease of use or handling, cost, active ingredients, and inert ingredients. Regardless of the form, they all have two similar functions. These functions include killing or inactivating microorganisms that are present within the water and to oxidize any organic contaminants introduced to the water by the bathers. Studies have shown that only 10% of chlorine is needed for sanitization while 90% of chorine is used for oxidation (Taylor Technologies, Inc., 2011). The oxidation-reduction potential (ORP) is a value that can be taken to evaluate a chlorines work value. These chlorines all have their advantages and disadvantages, but all produce a similar product, hypochlorous acid (HOCl) (Figure 1).

Figure 1. Comparison of chlorine sanitizers

Chlorine Gas

CHLORINE GAS + WATER → HYPOCHLOROUS ACID + MURIATIC ACID

[Cl_2] [H_2O] [HOCl] [HCl]

Advantages	Disadvantages
• least expensive chlorine sanitizer	• high capital costs required; feasible when pool is greater than 200,000 gallons • dangerous to handle; complex regulations and associated costs • lowers pH dramatically; destroys total alkalinity; high base demand

Sodium Hypochlorite

SODIUM HYPOCHLORITE + WATER → HYPOCHLOROUS ACID + SODIUM ION

[NaOCl] [H_2O] [HOCl] [Na^+]

Advantages	Disadvantages
• completely soluble in water • when sold as a bulk liquid, least costly source of chlorine outside of chlorine gas • clean product; no residue in pool water	• contains 90% water; bulky and heavy to handle; readily bleaches clothes/carpets • most alkaline chlorine sanitizer; significant acid demand • significant decomposition in storage

Figure 1. (continued)

Calcium Hypochlorite

CALCIUM HYPOCHLORITE + WATER → HYPOCHLOROUS ACID + CALCIUM ION (HARDNESS)

[$Ca(OCl_2)$] [H_2O] [HOCl] [Ca^{+2}]

Advantages	Disadvantages
• easily handled; compact source of chlorine • no significant storage decomposition • for soft water; significantly increases calcium hardness	• increases pH; high acid demand • for hard water; significantly raises calcium hardness • creates some turbidity due to inert insolubles

Lithium Hypochlorite

LITHIUM HYPOCHLORITE + WATER → HYPOCHLOROUS ACID + LITHIUM ION

[LiOCl] [H_2O] [HOCl] [Li^+]

Advantages	Disadvantages
• safest chlorine chemical to handle • completely soluble in water • dissolves quickly at normal pool temperatures • no premixing required; will not bleach vinyl liners at normal pool temperatures	• highest cost chlorine sanitizer • high TDS chemical due to significant inert content (71%)

Trichloro-s-triazinetrione [trichloroisocyanuric acid (TCCA)]

TCCA TABLETS + WATER → HYPOCHLOROUS ACID + STABILIZER

[TRICHLOR] [H_2O] [HOCl] [CYANURIC ACID]

Advantages	Disadvantages
• slow dissolving; good for chlorinators • convenient to use	• reduces total alkalinity • high base demand; requires addition of sodium bicarbonate • high-strength chlorine; readily supports combustion on contact with paper, rags, paint, oil, etc. • overstabilization possible

Figure 1. (continued)

Sodium Dichloro-s-triazinetrion [sodium dichloroisocyanurate (NaDCCA)]

NaDCCA GRANULES + WATER → HYPOCHLOROUS ACID + STABILIZER

[DICHLOR] [H_2O] [HOCl] [CYANURIC ACID]

Advantages	Disadvantages
• easily handled • little effect on pH; no acid or base demand	• most expensive stabilized chlorine • overstabilization possible

***Information from Figure 1 is based off information from the Taylor Technologies Pool & Spa Water Chemistry booklet.**

When adding any one of these chlorines to water, they produce the product of hypochlorous acid (HOCl). This is the vital chemical that inactivates the microorganisms and oxidizes the organics within the body of water. This is the free chlorine measurement that is taken (along with the much weaker OCl^-) to determine the effective level of chlorine residual that is in the body of water.

HOCl is a weak acid that has four main reactions it can go through that will negatively affect swimming pool sanitization (Taylor Technologies, Inc., 2011). The first reaction is the dissociation of HOCl. This reaction is highly dependent upon pH. As pH increases the HOCl can dissociate into the hydrogen ion (H^+) and the hypochlorite ion (OCl^-) as seen below.

$$HOCl \rightarrow OCl^- + H^+$$

Although OCl^- is considered an active sanitizer, it is much weaker than HOCl and has only 1% of its killing abilities. The second reaction that HOCl faces is its reaction with microorganisms and organics. After HOCl does its job of killing microorganisms or oxidizing organics, it will become an inactive chloride ion (Cl^-) and no longer effective in sanitizing. Thirdly, its reaction with ammonia produces irritating compounds called chloramines or combined chlorine. Chloramines are associated with the harsh chlorine smell and can irritate bather's eyes. Combined chlorine is also ineffective in killing recreational water diseases. The fourth reaction deals with how HOCl reacts to sunlight. The ultraviolet rays from the sun will reduce HOCl to an inactive chloride ion. This reaction can reduce active chlorine by up to 90% on a sunny day within two hours (Taylor Technologies, Inc., 2011). The reaction below shows how photolysis takes place when hypochlorite is degraded by ultraviolet rays (hv symbolizes sunlight).

$$2OCl^- + hv \rightarrow 2Cl^- + O_{2(g)}$$

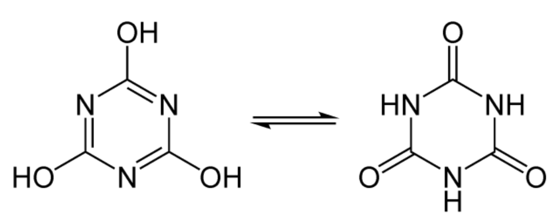
This fourth reaction is where cyanuric acid (CYA) is considered to play a very important role in protecting the free chlorine to allow it to perform its duty of sanitizing and oxidizing. In a simplified description, the cyanuric acid molecules in the water form a weak and temporary bond with the chlorine ions in the water during which time the ultraviolet energy from the sun cannot easily degrade the chlorine residual. This creates value in the chemical by allowing the chlorine to last longer in the pool. This stabilization, on the other hand, reduces the oxidation reduction potential (ORP) or work value of the chlorine (Williams, 1997). This now becomes a value versus risk debate.

This study will primarily focus on the impact CYA has on disinfection rates and at what levels are optimal for prime protection against recreational illnesses. It will look cyanuric acid's reputation as a defender of the degrading effect of UV against chlorine, and see why it may be seen as more of a money saver than a chemical that is used to protect swimmers against recreational illnesses. In fact, the more is better approach may not be the best way to look at adding cyanuric acid to a swimming pool. Perhaps the question that should be asked is where is a swimming pool's happy median when it comes to cyanuric acid level that allows a sufficient level of free chlorine to protect its swimmers against germs, yet does not bind the chlorine up to make it ineffective against recreational water illnesses. This paper will also look at the current and changing federal, state, and local regulations, and the perception amongst swimming pool professionals through interviews. The paper will try to evaluate how pool professionals become educated on using CYA to fully understand how to achieve the maximum effectiveness of chlorine while still benefit from its abilities to protect chlorine from the degrading affects of the sun's UV rays. Experiments will be conducted to grasp the correlation of CYA levels to the period of time it takes for ultraviolet rays of the sun to reduce HOCl to an inactive chloride ion and therefore a less effective sanitizer. Data should provide a hypothesis as to what level cyanuric acid would provide the optimum benefit. In the end, the study will present data why CYA may be one of the most controversial topics in the swimming pool industry today.

1.1 Physical Characteristics

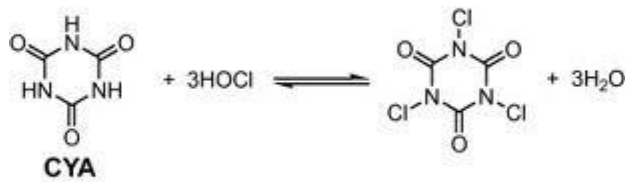
Cyanuric Acid is a white crystalline solid that can exist in the two structures shown in Figure 2.

Figure 2. Cyanuric Acid Structures (Wojtowicz, 2001)



1 2

Structure (1) is in the Enol form and structure (2) is in the Keto form. The Keto form predominates in the solid state whereas the Enol form predominates in solution (Wojtowicz, 2001). It's most important function in a swimming pool is to form a bond with UV senstive hypochlorous acid and protect it by absorbing the harmful UV rays. Below shows the relationship with trichloroisocyanuric acid (Trichlor) and its reaction products of HOCl and cyanuric acid (Baxter, 1994).



Cyanuric acid has a pH of 4.8 in a 1% solution and consequently will lower the pH of pool water. CYA is a slow dissolving compound and is not destroyed by other pool chemicals. Therefore CYA can only be removed by draining, splash-out, carry-out, and backwash. CYA can undergo biodegradation by some soil bacteria (Wojtowicz, 2001). CYA at a ratio of 1 lb./5,000 gallons (25 gr./1,000 liters) yields 25 ppm (Taylor Technologies, Inc., 2011).

Current research indicates cyanuric acid is basically non-toxic to humans, animals, and aquatic life (Wojtowicz, 2001). MSDS sheets for CYA state that the potential acute health effects are slightly hazardous in the case of skin contact, eye contact, ingestion, and inhalation (ScienceLab.com, Inc., 2012). The MSDS goes on to state that there are no known potential chronic health effects.

The actual toxicity of cyanuric acid is not the question at hand, but rather the issue is at what dose/rate of cyanuric acid does chlorine become a less effective sanitizer and oxidizer.

1.2 Testing and Regulations

To treat water properly, accurate analysis of the pool water composition first needs to be obtained. First, the pool water characteristics are dictated by various federal, state, and local regulations. This seems to be an area that does not have any definitive line. In the Wake County Environmental Services Swimming Pool Regulations document that governs commercial swimming pools for Wake County in North Carolina, there is no mention of what recommended cyanuric acid levels are to be maintained. The only reference of cyanuric acid is under Section 8(d) and that states "pools using cyanuric acid or chlorinated cyanurate shall provide a cyanuric acid test kit". There is only mention of sanitizer and pH minimum and maximum levels that commercial swimming pools are to be kept. The official certified pool operator (CPO) checklist for Wake County, NC does include cyanuric acid as an item to be tested on the document but does not specify a day or time it is needed to be tested. In an interview with Terry Chappell, the Section Chief of the Wake County Plan Review and Sanitation Program, he stated swimming pool operators are required by state rules to test cyanuric acid levels on a weekly basis. This though is not a responsibility for the county inspectors who visit the pools and that the burden only falls to the hands of the CPO that is on-site. Inspectors will only check for chlorine and pH levels during their inspection. If chlorine levels are not existent, than this could be an indicator of issues with cyanuric acid levels. CPO's will record cyanuric acid information on the Wake County pool inspection sheet and keep for their records (Chappell, 2013). Chappell also stated that the K-2005 Taylor complete test kit is recommended for testing and what is used when his inspectors test water chemistry for commercial swimming pools (Figure 3).

Figure 3. Wake County inspectors test kit for commercial swimming pools. Picture from Taylor Technologies website of K-2005 Complete Test Kit.

The cyanuric acid test in the K-2005 test kit is based on a turbidity reading (Taylor Technologies, Inc., 2013). This means that water clarity is measured to determine the amount of suspended material is within the test. Figure 4 shows the process on how the turbidity reading is taken. To perform this test, Taylor Technologies instructs the tester to perform these functions:

- Rinse and fill the cyanuric acid dispensing bottle to the 7mL mark with sample water.
- Add the Cyanuric Acid Reagent (R-0013) to the 14mL mark. Cap and mix for 30 seconds.
- Slowly transfer the cloudy solution that develops to the small comparator tube while viewing from the top.
- Stop when the black dot on the bottom of the small comparator tube disappears
- Check the liquid level on the back of the comparator block. The reading indicates a parts per million concentration of cyanuric acid.

Figure 4. These pictures show the process of the turbidity test for reading cyanuric acid levels in the Taylor K-2005 complete test kit

Figure 5 shows how the reading on the back of the comparator block is taken. This parts per million reading is taken when the “end test” in Figure 4 is reached.

Figure 5. Picture of comparator with cyanuric acid level s displayed in parts per million.

In the Terry Chappell interview, he stated that maximum CYA levels were not to go over 100ppm (Chappell, 2013). This is in accordance to Section 15A NCAC 18A .2535 of the North Carolina Department of Environment and Natural Resources proposed rules for public swimming pools which also states swimming pools using chlorine and are not outdoors or swimming pools that require stabilized chlorine shall not exceed cyanuric acid levels greater than 100ppm. This state rule further stated that test kits for measuring cyanuric acid shall be kept on site and carried out on weekly basis. Chappell went on to say that once over 100ppm the swimming pool would need to be drained and refilled. He mentioned that some operators will partially or half drain the swimming pool and have success with the influx of fresh water re-establishing the proper cyanuric acid limits. He feels that this is a waste of time and effort though and the best thing to do is to just drain and start over. He went on further to say that Wake County recommends cyanuric acid levels to be maintained between 30ppm to 50ppm.

In further research on state regulations, 49 states (exception Alaska) were looked at to see what the maximum levels of cyanuric acid were acceptable. Of these 49 states, there were a total of 12 different values that were considered state maximum cyanuric acid levels. These values ranged from 0ppm to 150ppm as the acceptable levels. Nearly 47% of the states in the U.S., along with North Carolina, used the 100ppm value as their maximum allowable level. This fell in line with what the Nation Swimming Pool Foundation's recommendation of 10ppm to 100ppm (Cantu, 2005). New York was the only state that did not allow usage of the chemical, while Arizona, Maine, and Oregon were at the high end of the spectrum with 150ppm as their maximum allowable cyanuric acid level. Eight of the 49 states had no mention of cyanuric acid levels in their water quality standards section for swimming pools. Of these eight, Alabama and Vermont actually stated that they did not regulate the chemical at all.

In a survey of fifteen professional pool companies from across central and eastern North Carolina, there were also variations on what cyanuric acid levels should be within a swimming pool. Of fifteen values taken for recommended maximum levels of cyanuric acid, there were six different values given. The highest maximum level given was 100ppm and the lowest maximum level given was 50ppm. The value of 50ppm was given six times which was 40% of the responses received (Table 1). This level is half the 100ppm maximum level recommended by nearly half of the United States. When the companies were asked the question of what the North Carolina state regulations were on cyanuric acid levels twelve of the fifteen companies stated they knew that once levels reached over 100ppm their pools would need to be drained an refilled. Three of the companies surveyed were unsure of what the maximum level was that was required by state regulation.

Table 1 Maximum Recommend Level of Cyanuric Acid by NC Pool Companies

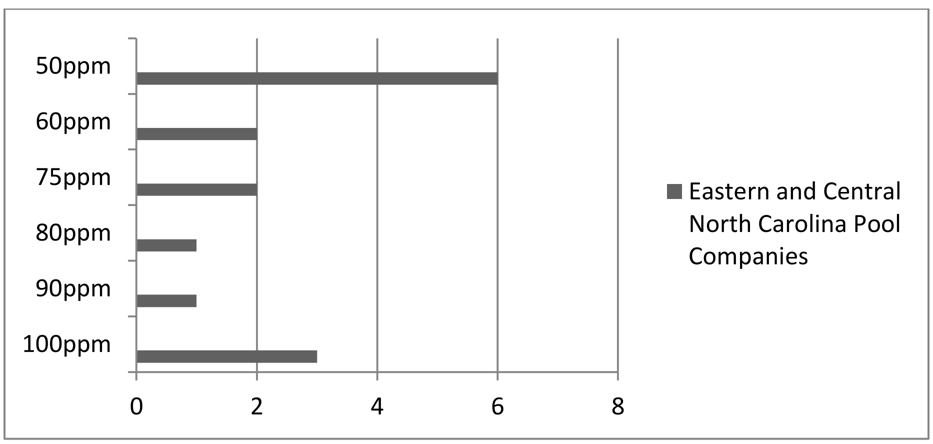


Table based of information taken from a survey of fifteen pool companies in eastern and central NC (Askins, 2013)

The minimum levels recommended by the fifteen surveyed pool companies in North Carolina also had variations as well. The range for minimum recommended levels went from 30ppm to 80ppm with 40ppm being given 40% of the time. The second highest value of 50ppm was answered in 33% of the responses. It can be taken from this data that most of the pool companies surveyed seemed to want to keep the cyanuric acid levels in the area of 50ppm.

In the various responses throughout these surveys and interviews, it was noted numerous times that pool companies seemed to have cyanuric acid issues late in the summer. These companies stated levels would reach beyond their recommended maximum levels and close to or beyond the North Carolina state recommended levels. They stated that this issue was due to using Trichlor or Dichlor as their main source for sanitization. Using this stabilized product kept a constant influx of cyanuric acid being introduced to the pool, and without new water being added the levels of cyanuric acid would therefore increase. These pool companies were also asked if there were any issues noticed once cyanuric acid levels reached a certain point. 40% of the responses to this question stated that they noticed no issues once cyanuric acid levels were beyond their recommended level. Five of fifteen responses noted that issues seemed to come about once levels reached 100ppm. The issues that occurred were green pools from algae growth or clarity issues with the water. All the companies that had issues due to high cyanuric acid levels felt they occurred from ineffective chlorine levels. As the interviewer for these surveys, it felt that most of these pool companies did not think cyanuric acid use was a major issue. Companies felt that as long as pH and chlorine were in their needed ranges, the swimming pool would be considered a safe place and recreational water illnesses a non-issue. This also validated the Terry Chappell interview response on a correlation of cyanuric acid level issues and recreational water illness occurrences. Chappell did not know of any recreational water illness occurring in Wake County due to a cyanuric acid level issue and there were no records on file that indicated so (Chappell, 2013).

2. Methods

2.1 Cyanuric Acid and UV Effect on Free Chlorine Readings

A determination on how long it takes the ultraviolet rays of the sun to degrade HOCl will help in providing the foundation of the value of longevity versus the risk of low activity when using cyanuric acid. To do this a test will be done with seven samples of water that will simulate seven different swimming pools without a bather load. The seven samples of water will be held in 5-gallon containers that will be chemically balanced in accordance with the National Swimming Pool Foundation Handbook Water Chemistry Guidelines for public swimming pools. These initial samples of water were filled using tap water. This source water had a pH of 8.2, a total alkalinity of 30ppm, a free chlorine level of 2ppm, and a calcium hardness level of 30ppm. Each value was determined using the Taylor 2005 test kit. The water was then balanced using the Regal and Refresh chemical line in accordance to the National Swimming Pool Foundation Handbook Water Chemistry Guidelines (Taylor Technologies, Inc., 2011). Outside temperatures were not ideal, so the water was kept inside and covered with a lid to prevent contaminants from entering and to allow water temperature to reach close to the recommended 78˚F as possible. This was done the day prior when temperatures were forecasted to be close to 80˚F and full sunshine on the following day. The pH was brought to a level of 7.4-7.6 for each sample. This was done using Regal pH Minus (93.2% sodium bisulfate) to adjust the pH down from 8.2. Total alkalinity was raised to 100-120ppm using Regal Alkalinity Increaser (100% sodium hydrogen carbonate), and calcium hardness was raised to 150ppm using Regal Calcium Increaser. After the water was chemically balanced to the National Swimming Pool Foundation

Handbook Water Chemistry Guidelines in each of the seven 5-gallon containers, cyanuric acid was added at various levels to achieve different parts per million readings. These values were set at 0ppm, 15ppm, 35ppm, 55ppm, 75ppm, 100ppm, and 150ppm. Free chlorine was set at 3ppm using Refresh 73% calcium hypochlorite just before the 5 gallon containers were to be set outside and exposed to direct sunlight. Each container was labeled with a number 1 through 7 to be able to record data for each sample. Each bucket was then retested with the K-2005 Taylor test kit to confirm test readings were accurate and then recorded under each samples number. The below table (Table 2) is the initial recorded data for each sample.

Table 2. Initial Chemistry and Temperature Readings (9am)

Bucket #	pH	TA	CYA	Initial FC
1	7.5	100	15	3
2	7.4	100	35	3
3	7.4	100	55	3
4	7.5	100	75	3
5	7.5	120	100	3
6	7.4	120	150	3
7	7.6	100	0	3

Initial Air Temperature: 51˚F

Initial Water Temperature: 68˚F

These samples were all placed outside at 9am in direct sunlight. At this time, an assumption was also made on the percentage of direct sunlight reaching the exposed surface water. Due to the angle of the sun and the lip of the container, it was assumed at 9am that only 25% of the direct sunlight was reaching the surface water. After the initial reading at 9am, each water sample would be stirred and then be tested every hour for a free chlorine reading using the K-2005 Taylor test kit. During this time an air temperature and water temperature reading would also be taken. In addition, an observation would be made on the amount of direct sunlight assumed to be reaching the exposed surface water of the sample. If the percent of sunlight was not 100% a note was made on the record as to the reason why the exposure was limited. These readings would be taken from 9am to 7pm each hour at the beginning of the hour. Table 3 shows the recorded data that was taken during this 10 hour period of free chlorine readings.

Table 3. Hourly Recorded Free Chlorine Readings and Observations

	Free Chlorine Readings										
Bucket #	9am	10am	11am	12am	1pm	2pm	3pm	4pm	5pm	6pm	7pm
1	3	2.5	2	2	1.5	1	1	0.5	0.5	0.25	0
2	3	3	2.5	2.5	2	1.5	1.5	1	1	0.75	0.75
3	3	3	3	2.5	2.5	2	2	1.5	1.5	1.5	1.25
4	3	3	3	3	2.5	2	2	2	1.5	1.5	1.5
5	3	3	3	3	3	2.5	2.5	2	2	2	2
6	3	3	3	3	3	3	2.5	2.5	2.5	2.5	2.5
7	3	2	1.5	0.5	0	0	0	0	0	0	0
% Sunlight	25%	50%	80%	90%	100%	100%	90%	70%	50%	20%	0%
Air Temp.	51˚F	58˚F	65˚F	70˚F	74˚F	76˚F	78˚F	78˚F	75˚F	73˚F	70˚F
Water Temp.	68˚F	68˚F	69˚F	71˚F	76˚F	80˚F	80˚F	80˚F	80˚F	77˚F	76˚F
*9am notes: Shadow of bucket rim from sun caused 75% shadow on surface water.											
*10am notes: Shadow of bucket rim from angle of sun caused 50% shadow of surface water.											
*11am notes: Shadow of bucket rim from angle of sun caused 20% shadow of surface water											
*12pm notes: Shadow of bucket rim from angle of sun caused 10% shadow of surface water.											
*3pm notes: Shadow of bucket rim from angle of sun caused 10% shadow of surface water.											
*4pm notes: Shadow of bucket rim from angle of sun caused 30% shadow of surface water.											
*5pm notes: Shadow of bucket rim and high clouds moving in caused 50% shadow of surface water.											
*6pm notes: High clouds had moved in. Assumption of 80% blockage of direct sun rays.											
*7pm notes: Thin layer of clouds with sun setting gives the assumption of 100% blockage of direct sun rays.											

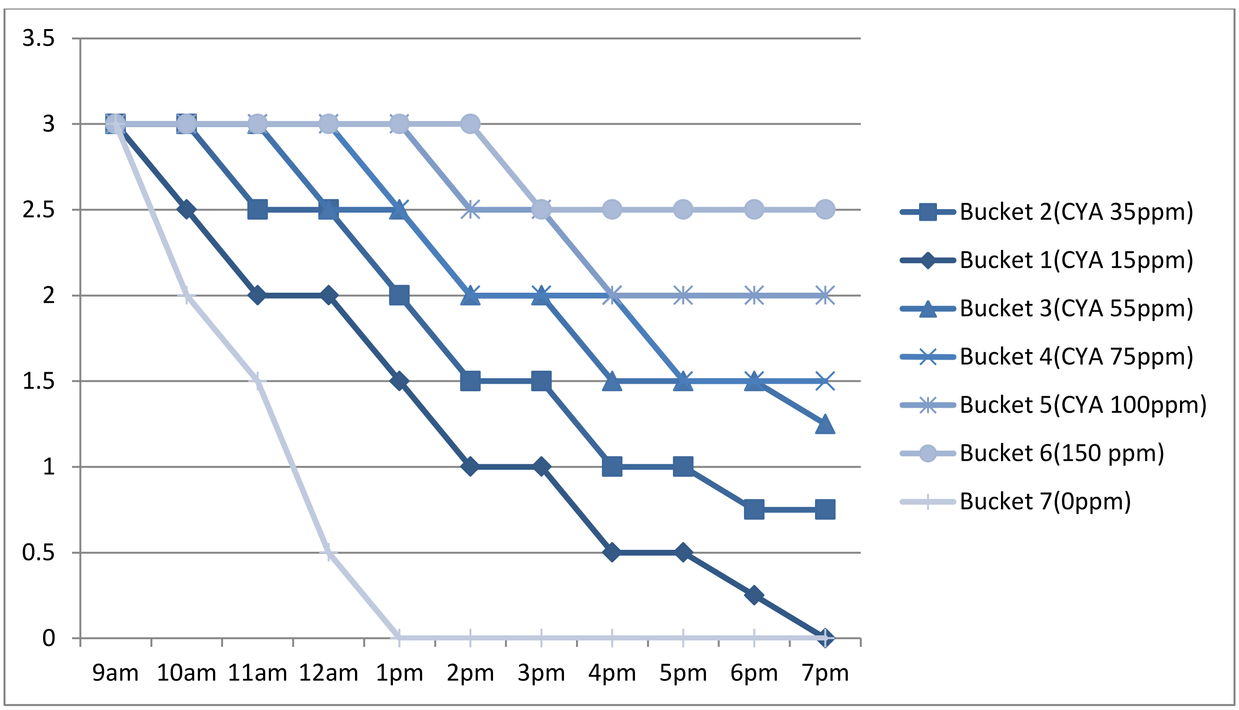
* Readings were taken on April 7th, 2013 in Knightdale, North Carolina.

The recording of data was ended at 7pm due to the accumulation of high clouds and the setting sun reducing the direct rays of the sun to nearly 0% on the exposed surface water of each container. The readings in Table 3 should simulate what ultraviolet rays do to HOCl in swimming pools balanced according to the National Swimming Pool Foundation, but without the normal bather loads that would further tax the abilities of chlorine's sanitizing and oxidizing abilities.

3. Results

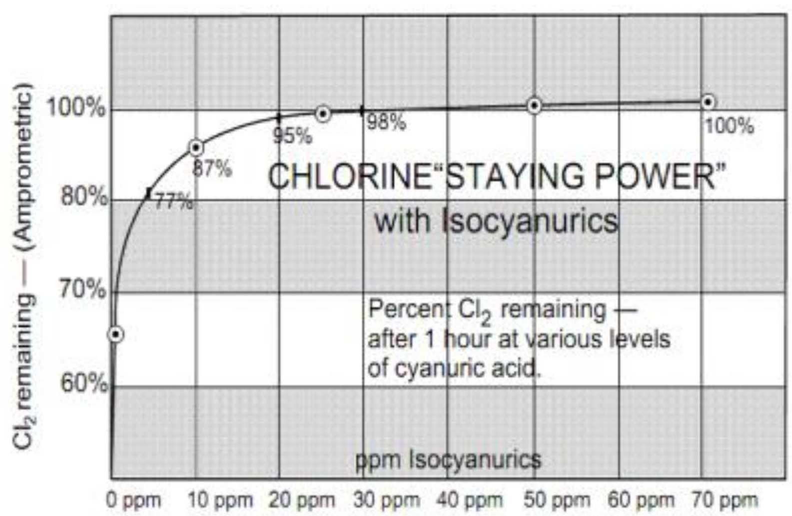
Figure 6 displays the results of the free chlorine readings after exposure to the ultraviolet rays of the sun for 10 hours. As expected the free chlorine level readings for the sample containing no cyanuric acid was reduced fairly quickly. Its free chlorine readings went from 3ppm to 0ppm

Figure 6. Graph of Free Chlorine Readings in Relationship to Cyanuric Acid Levels over a 10 Hour Period of Exposure to Ultraviolet Rays (Data taken from test performed on 4/7/13).



within four hours. All containers except samples #1 (15ppm cyanuric acid) and #7 (0ppm cyanuric acid) experienced no reduction of free chlorine levels at the 10am testing. I compared this result to a one-hour test performed on chlorine "staying power" that was taken from a paper written by Kent Williams called *CYA, Benefactor or Bomb* (Figure 7). This information, which was based from data taken from technical bulletins of a major specialty chemical manufacturer, demonstrated that chlorine readings remained at 100% when cyanuric acid levels were above 30ppm or higher. This was very similar to the readings that was taken on the

Figure 7. Chlorine "Staying Power" After One Hour at Various Cyanuric Acid Levels

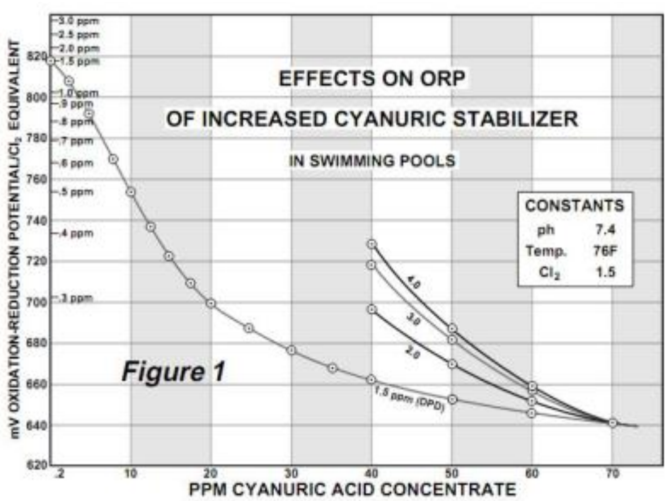


This information was taken from the paper CYA, Benefactor or Bomb written by author Kent Williams. It shows what percent of free chlorine remained after one hour at various ppm levels of cyanuric acid.

test performed on 4/7/13 and backed up the data that was recorded. It also shows that over 20ppm cyanuric acid provides little return in chlorine "staying power". At the 11am reading, sample #2 (cyanuric acid 35ppm) experienced its first reduction of free chlorine while #1 and #7 samples continued to have free chlorine levels reduced. Sample #3 (cyanuric acid 55ppm) recorded its first reduction in free chlorine at noon. Sample #4 (cyanuric acid 75ppm) experienced its first reduction in free chlorine at 1pm. Sample #5 (cyanuric acid 100ppm), which was set at the North Carolina state maximum level for cyanuric acid recorded its first reduction at 2pm. Sample #6 (cyanuric acid 150ppm), which is the highest maximum level set by some of the states in the country, was the final to have a free chlorine reduction at 3pm. Other than sample #7 at 0ppm, the only other sample to have free chlorine reduced to zero in this 10-hour period was sample #1 with a cyanuric acid level at 15ppm. Sample # 2 had a final free chlorine reading of .75ppm at the end of the 10-hour test, which is below the National Swimming Pool Foundation CPO Handbook minimum standards of 1ppm. Samples #3, #4, #5, and #6 all had free chlorine levels that exceeded these standards after the 10-hour test.

Next data was gathered on how cyanuric acid affects ORP, which was defined earlier as a way

Figure 8. Effects on ORP of Increased Cyanuric Acid Levels



This figure taken from *CYA, Benefactor or Bomb* displays the effects cyanuric acid has on ORP values.

to evaluate a chlorine's work value or its effectiveness. This value, according to the Association of Pool & Spa Professionals (APSP) suggested chemical operational parameters, needs to be at a minimum value of 650mV.   According to an Oregon study, only ORP levels could be linked to consistently be able to predict the sanitation of the swimming pool. Other tests including levels of pH, free chlorine residuals, cyanuric acid, clarity, total dissolved solids (TDS), or chloramines could not predict how well a pool was sanitized (Williams, 1997). Figure 8 above, which was a table also taken from the paper *CYA, Benefactor or Bomb*, shows the effects cyanuric acid can have on the ORP values. Looking at this figure, it can be seen that cyanuric acid levels at 5ppm can reduce chlorine effectiveness over 35%, while levels at 10ppm and 20ppm can reduce effectiveness nearly 65% and 80% respectively (Williams, 1997). Looking at this further according to Williams, beyond a cyanuric acid level of 25ppm, it can be expected that ORP can experience about 10% more in reduction with very little gain in retention over the first hour according to Figure 7. Figure 8 shows the chlorine's potential to oxidize, not necessarily what is needed to handle the load of organic contaminants within the water of the swimming pool. The load of organic contaminants can be a large variable depending on many things such as the number of bathers, cleanliness of the bathers, leaves, animals, etc. Williams states that Figure 8 shows a flattening of the curve of at various ppm of free chlorine levels occurs at a level of 70ppm cyanuric acid. This is where no additions of chlorine will make any difference in the resultant level of ORP. This basically shows that any level of chlorine will result in about .2ppm effectiveness (Williams, 1997). This information means that the chlorine level will remain longer, but its effectiveness will not get any better.

Based on information from Figure 8 and the survey taken from fifteen different professional pool companies, where approximately 70ppm cyanuric acid is the average maximum value that most companies wanted to be near, free chlorine levels at 1.5ppm or higher would have the ORP reading just slightly below (640mV) the acceptable minimum according to the APSP. Only six of the companies that said their maximum level of cyanuric acid is 50ppm would come in above this acceptable ORP level. Wake County's Plan Review and Sanitation Program Section Chief Terry Chappell's recommendation of 30ppm to 50ppm cyanuric acid as an ideal range for commercial swimming pools, which is also the National Swimming Pool Foundation ideal range recommendation, would also fall in above the acceptable APSP minimum ORP value.

4. Conclusion

Data taken from the tests performed on the length of time free chlorine takes to go through photolysis at various levels of cyanuric acid and information on what these various levels of cyanuric acid can do to the ORP of chlorine can help zero in on what acceptable levels of cyanuric acid should be for commercial swimming pools that require stabilized chlorine. It was determined that the "staying power" of chlorine has diminishing returns once cyanuric acid levels reached much over 20ppm. It was also determined that once the cyanuric acid levels reach 70ppm there are no additional gains in chlorine effectiveness no matter what additional amounts of chlorine are added to the swimming pool. This narrows down the ideal range for cyanuric acid levels to be somewhere between 20ppm to 70ppm. Of course certain swimming pools face different variables of direct sunlight and loads of organic contaminants that may affect the exact level that would be recommended within this range. This is where the expertise of the pool professional comes into play by knowing how to test the chemicals in the swimming pool and adjusting the parameters in which the chemicals make sense for proper sanitization. This can definitely be a fine line that needs to be walked to make sure all chemical levels are kept within the parameters of the regulations set forth in the state of residence.

In pools where cyanuric acid levels seem to be a continual problem for the pool professional, alternatives may need to be addressed. Unstabilized chlorine alternatives, such as calcium hypochlorite erosion feeders and sodium hypochlorite pumps, may present advantages that may outweigh their disadvantages when cyanuric acid issues continually cause problems. These type of systems can provide predictable rates of chlorine that can be adjusted to suit the different variables a swimming pool may face to allow proper sanitization. The only issue is that high costs can sometimes play a role with these systems and may not be within the budget of an owner/operator.

Variances in state regulations also appear to be rather inconsistent when stating minimum and maximum levels, along with ideal ranges that cyanuric acid levels should be kept. When states range from 0ppm to 150ppm on a maximum acceptable level, it shows no uniformity and could become confusing to individuals in the pool business that do not have the training to understand what this chemical does. An ideal range for cyanuric acid levels that falls within 20ppm to 70ppm should be set in place, and the individual testing of ORP levels in commercial swimming pools should be done to help further define where the ideal parameters for certain pools should be. This will help to protect itself from the threat of recreational water illnesses.

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