How Much Free Chlorine Do You Really Need?

By Robert W. Lowry

If you look at any guideline or standard or check with any health code, you will see that almost all of them recommend a free chlorine (FC) level of 2.0 to 4.0 ppm.

This gives rise to the idea that if you measure free chlorine in the water and it is between 2.0 and 4.0 ppm then the water is OK or safe. It may or may not be. There is a way to know how much free chlorine you need in any pool.

The answer is FC needs to be a minimum of 7.5% of the CYA level – unless supplements are used.

And here are the reasons why.

Bacteria and Algae Reproduction

Bacteria take about 15 to 60 minutes to double in population under ideal conditions. For instance, the growth rate for E. coli is 15-20 minutes. Algae can double in population in about 3 to 8 hours. To prevent uncontrolled growth, the kill rate must exceed the growth rate for bacteria or algae. Specifically, that means killing more than half of the bacteria or algae in the time that it takes bacteria or algae to double in population. It is more difficult to kill algae than bacteria. Therefore it stands to reason that if we kill the algae we will have also killed the bacteria.

HOCl and OCl^-

Before discussing how much FC is needed let's review what happens to chlorine when it is added to water. When we add chlorine in any form to water, a rapid reaction takes place that produces hypochlorous acid (HOCl). Here is what happens when chlorine is added to water:

$Cl_2 + H_2O \rightarrow \mathbf{HOCl} + HCl$

chlorine and water forms **hypochlorous acid** and hydrochloric acid

A second reaction is nearly instantaneous: Hypochlorous acid (HOCl) produced by adding any type of chlorine dissociates (comes apart into its ions) according to the following equation:

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

hypochlorous acid dissociates into hydrogen ion and hypochlorite ion

HOCl is the faster killing form of chlorine in water. OCl^- kills but it is 30-300 times less effective than HOCl depending on conditions and organisms. The pH of the water determines how much of the FC is in the HOCl and OCl^- forms. When the pH of the water is low there is more HOCl. When the pH is high there is less HOCl. When the pH is 7.2, the HOCl is about 65% of the FC. At a pH of 7.5 the HOCl is about 48% of FC and at pH 7.8 the HOCl is about 32% of FC.

It Takes a Small Amount of HOCl to Kill Algae and Bacteria

It doesn't really take much FC to kill bacteria and algae. The World Health Organization (WHO) suggests the minimum HOCl for disinfection is 650 mV at a pH of 7.5 which corresponds roughly to about 0.01 to 0.05 ppm of HOCl depending on the ORP instrument that is used. Killing green and black algae requires at least 0.02 to 0.03 ppm of HOCl. Therefore any amount of HOCl less than 0.01 ppm will not kill algae and an amount of HOCl between 0.01 and 0.050 ppm HOCl might kill algae. In any case, **HOCl greater than 0.050 ppm will kill algae according to many sources.**

Chlorine Binds to CYA and Slows Down Kill Times

When chlorine and CYA (cyanuric acid) are in the water, the chlorine binds to CYA and that is determined by chemical equilibrium. The slowdown in kill times is significant. HOCl, OCl^- and all forms of chlorine bound to CYA together are free chlorine (FC) and total chlorine (TC)**. It is up to you to know how much of the chlorine that is in the water is in the killing form (HOCl). This requires knowing the pH and CYA level in addition to FC.**

Chlorine combines with CYA to form new chemicals – chlorinated isocyanurates. These new chemicals are not significant disinfectants or oxidizers. They are at least 150 times less effective. In other words, they don't kill or oxidize much of anything. CYA has a strong affinity for chlorine so most of the chlorine in the water is bonded to CYA.

There are 6 different chlorine-CYA reaction compounds. The following is the primary relevant chemical equation:

$$Cl_2C_3N_3O_3^- + H_2O \rightleftarrows HOCl + H_2C_3N_3O_3^-$$

chlorine bound to cyanuric acid and water forms hypochlorous acid and cyanurate ion

Notice that there are two arrows. This is because the reaction can go in either direction (equilibrium). Also, for illustration purposes, the arrow pointing to the left is larger than the arrow pointing to the right. This is because at typical CYA levels in a pool, the vast majority of chlorine is bound to CYA

In fact, at a pH of 7.5 and a CYA of 30 ppm, 97.2% of the chlorine is bound to CYA. Therefore, with a pH of 7.5 there is only about 1.5% hypochlorous acid (HOCl), and 1.5% hypochlorite ion (OCl^-) available for disinfecting and oxidizing. Remember that at a pH of 7.5, there is about 50% HOCl and 50% OCl^-.

Based on the amount of chlorine bound to CYA and based on the pH of the water we can calculate if there is more than the 0.05 ppm of HOCl that is needed to kill algae in the water.

Here are some charts showing the amounts of HOCl available at a pH 7.2, 7.5 and 7.8 and various CYA concentrations.

Green = Algae are killed (HOCl >0.05 ppm)
Orange = Algae might be killed (HOCl >0.01 but <0.05 ppm)
Red = Algae are NOT killed (HOCl <0.01 ppm)

FC 2.0 ppm, pH 7.2 and Temp 80° F			
CYA ppm	HOCl ppm	OCl ppm	HOCl Available
0	1.286	0.714	64.30 %
10	0.106	0.059	5.30 %
20	0.048	0.027	2.40 %
30	0.031	0.017	1.55 %
40	0.023	0.013	1.15 %
50	0.018	0.010	0.90 %
60	0.015	0.008	0.75 %
70	0.013	0.007	0.65 %
80	0.011	0.006	0.55 %
90	0.010	0.005	0.50 %
100	0.009	0.005	0.45 %
150	0.006	0.003	0.30 %
200	0.004	0.002	0.20 %

FC 3.0 ppm, pH 7.2 and Temp 80° F			
CYA ppm	HOCl ppm	OCl ppm	HOCl Available
0	1.930	1.070	64.33 %
10	0.185	0.103	6.17 %
20	0.078	0.043	2.60 %
30	0.049	0.027	1.63 %
40	0.035	0.020	1.17 %
50	0.028	0.015	0.93 %
60	0.023	0.013	0.77 %
70	0.019	0.011	0.63 %
80	0.017	0.009	0.57 %
90	0.015	0.008	0.50 %
100	0.013	0.007	0.43 %
150	0.009	0.005	0.30 %
200	0.007	0.004	0.23 %

FC 4.0 ppm, pH 7.2 and Temp 80° F			
CYA ppm	HOCl ppm	OCl ppm	HOCl Available
0	2.573	1.427	64.33 %
10	0.289	0.160	7.23 %
20	0.112	0.062	2.80 %
30	0.068	0.038	1.70 %
40	0.049	0.027	1.23 %
50	0.038	0.021	0.95 %
60	0.031	0.017	0.78 %
70	0.027	0.015	1.68 %
80	0.023	0.013	0.58 %
90	0.020	0.013	0.50 %
100	0.018	0.010	0.68 %
150	0.012	0.001	0.30 %
200	0.001	0.005	0.02 %

FC 2.0 ppm, pH 7.5 and Temp 80° F			
CYA ppm	HOCl ppm	OCl ppm	HOCl Available
0	0.949	1.051	47.45 %
10	0.091	0.100	4.55 %
20	0.041	0.046	2.05 %
30	0.027	0.029	1.35 %
40	0.020	0.022	1.00 %
50	0.015	0.017	0.75 %
60	0.013	0.014	0.65 %
70	0.011	0.012	0.55 %
80	0.010	0.011	0.50 %
90	0.008	0.009	0.40%
100	0.008	0.008	0.40 %
150	0.005	0.006	0.25 %
200	0.004	0.004	0.20 %

FC 3.0 ppm, pH 7.5 and Temp 80° F			
CYA ppm	HOCl ppm	OCl ppm	HOCl Available
0	1.435	1.565	47.83
10	0.158	0.175	5.27 %
20	0.067	0.074	2.23 %
30	0.042	0.046	1.40 %
40	0.030	0.034	1.00 %
50	0.024	0.026	0.80 %
60	0.020	0.022	0.67 %
70	0.017	0.017	0.57 %
80	0.015	0.015	0.50 %
90	0.013	0.014	0.43 %
100	0.012	0.013	0.40 %
150	0.008	0.008	0.27 %
200	0.006	0.006	0.20 %

FC 4.0 ppm, pH 7.5 and Temp 80° F			
CYA ppm	HOCl ppm	OCl ppm	HOCl Available
0	1.898	2.102	47.45 %
10	0.248	0.274	6.20 %
20	0.097	0.107	2.43 %
30	0.059	0.065	1.48 %
40	0.042	0.047	1.05 %
50	0.033	0.036	0.83 %
60	0.027	0.030	0.68 %
70	0.023	0.025	0.58 %
80	0.020	0.022	0.50 %
90	0.017	0.019	0.43 %
100	0.016	0.017	0.40 %
150	0.010	0.011	0.25 %
200	0.008	0.008	0.20 %

FC 2.0 ppm, pH 7.8 and Temp 80° F			
CYA ppm	HOCl ppm	OCl ppm	HOCl Available
0	0.623	1.377	31.15 %
10	0.079	0.176	3.95 %
20	0.037	0.082	1.85 %
30	0.024	0.053	1.20 %
40	0.018	0.039	0.90 %
50	0.014	0.031	0.70 %
60	0.012	0.026	0.60 %
70	0.010	0.022	0.50 %
80	0.009	0.019	0.45 %
90	0.008	0.017	0.40 %
100	0.007	0.015	0.35 %
150	0.005	0.010	0.25 %
200	0.003	0.008	0.15 %

FC 3.0 ppm, pH 7.8 and Temp 80° F			
CYA ppm	HOCl ppm	OCl ppm	HOCl Available
0	0.935	2.065	31.17 %
10	0.138	0.304	4.60 %
20	0.060	0.132	2.00 %
30	0.038	0.084	1.27 %
40	0.028	0.061	0.93 %
50	0.022	0.048	0.73 %
60	0.018	0.040	0.60 %
70	0.015	0.034	0.50 %
80	0.013	0.029	0.43 %
90	0.012	0.026	0.40 %
100	0.011	0.023	0.37 %
150	0.007	0.015	0.23 %
200	0.005	0.011	0.17 %

FC 4.0 ppm, pH 7.8 and Temp 80° F			
CYA ppm	HOCl ppm	OCl ppm	HOCl Available
0	1.246	2.754	31.15 %
10	0.212	0.468	5.30 %
20	0.087	0.191	2.18 %
30	0.053	0.118	1.33 %
40	0.038	0.085	0.95 %
50	0.030	0.066	0.75 %
60	0.025	0.054	0.63 %
70	0.021	0.046	0.53 %
80	0.018	0.040	0.45 %
90	0.016	0.035	0.40 %
100	0.014	0.031	0.35 %
150	0.009	0.021	0.23 %
200	0.007	0.015	0.18 %

The first three charts (reading across) are for a pH of 7.2. For a FC of 2.0 ppm, algae are killed with a CYA of 0 and 10 ppm indicated by the green numbers. At 3.0 FC, algae are killed with up to 20 ppm CYA. And at 4.0 FC, algae are killed with up to 30 ppm CYA. You can also see that algae are not killed with even 4.0 ppm FC when CYA is more than 40 ppm and the pH is 7.2.

The next three charts (reading across) are for a pH of 7.5. For a FC of 2.0, algae are killed with a CYA of 0 and 10 ppm CYA indicated by the green numbers. At 3.0 FC, algae are killed with up to 20 ppm CYA. And at 4.0 FC, algae are killed with up to 30 ppm CYA. You can see that algae are not killed with even 4.0 ppm FC when CYA is more than 40 ppm and the pH is 7.5.

Please understand that the amount of chlorine bound to CYA and the amounts as $HOCl$ and OCl^- are in equilibrium. This means that as some $HOCl$ is used it is replaced by some OCl^- and some chlorine that is bound to CYA becomes free chlorine. So if there is 1.0% of the FC in the water as $HOCl$ there will always be 1% until all the FC is used. You can think of the amount of chlorine bound to CYA as a reservoir of free chlorine. We need to make sure that the 1% is enough to kill algae – greater than 0.05 ppm $HOCl$.

Looking at these charts to figure out if you have enough FC to kill algae in any given pool is tedious and it means you would need to refer to the charts all the time. Here is an easier way.

Free Chlorine must be a minimum of 7.5% of the CYA level.

If you have 50 ppm of CYA then you need 3.75 ppm FC minimum ($50 \times 0.075 = 3.75$). If you have 70 ppm CYA then you need 5.25 ppm FC ($70 \times 0.075 = 5.25$). By having FC at 7.5% of CYA, the amount of HOCl will be more than the 0.05 ppm $HOCl$ needed for algae control.

Of course, having a FC of more than 5.0 ppm is not recommended. When CYA is more than about 70 ppm, you should drain some water so that an FC level of 7.5% of the CYA will be below 5.0 ppm.

What If CYA Is Not Used?

Looking at the above charts, you might be asking yourself what if I don't use CYA. The answer is you could but it would be expensive and require that you add chlorine multiple times per day. The real world UV degradation of chlorine in a swimming pool is about 75% loss in 2 hours. The next 2 hours the loss is 75% of that. The chlorine that you added will be almost zero in 4 hours. Let's say you start with 4.0 ppm FC. In 2 hours you lose 75% of 4.0 or about 3.0 ppm is gone. In the next 2 hours you lose 75% of 1.0 ppm or 0.75 ppm. Now you have only 0.25 ppm FC. In 4 hours you basically have no free chlorine in the water.

Also, it would be unrealistic to maintain 0.1 ppm FC in a pool by using 1-2 ppm FC or more with no CYA. At this level of FC, swimsuits, skin and hair are oxidized faster, equipment corrodes faster and chloramines and nitrogen trichlorides are created faster.

CYA slows down the FC loss due to UV degradation from sunlight and significantly moderates chlorine's strength. In fact, 30 ppm of CYA keeps chlorine in the water 8 times longer than without it.

CYA Increases

If trichlor is being used as a regular chlorinating source then the CYA is going to be increasing rapidly. For each 10 ppm of FC there will be an increase in CYA of 6.0 ppm. The average pool in summertime sun loses about 1.5 to 2.0 ppm FC per day just due to sunlight. So in a week, the loss is 10 to 14 ppm of FC. This will mean that if trichlor is used, the CYA will increase by 6 to 8.5 ppm per week. This also means that the FC level would need to be increased by about 0.5-0.6 ppm each week to prevent algae (more than 0.05 ppm HOCl). If the CYA level goes up and the FC level is not raised to compensate then there may not be enough FC to kill algae. This may be one of the reasons that a pool is fine at the beginning of summer but as the CYA increases there will be a point at which the HOCl level (less than 0.05 ppm) is insufficient to prevent algae growth. If a pool is low in algae nutrients such as phosphates or nitrates or if algaecides are being used, then a pool may not grow algae even though the HOCl level is below 0.05 ppm.

Using Hypochlorite Does Not Raise pH or CYA

If you use liquid chlorine (sodium hypochlorite), liquid bleach (sodium hypochlorite), cal hypo (calcium hypochlorite) or lithium hypo (lithium hypochlorite) for regular chlorination, the CYA will not increase so you can keep a level of 30-50 ppm. Also, all of these hypochlorites have a net zero effect on pH. If you use hypochlorite, the pH of the pool water will not go up except a small amount from the excess lye (sodium hydroxide) in the product to make the chlorine last longer in storage. The reason is that when you initially add one of these hypochlorites the pH goes up because the hypochlorite forms hypochlorous acid HOCl. But when the hypochlorous acid is used or destroyed by sunlight the reaction creates HCl (hydrochloric acid) which offsets the original rise in pH except for the excess of lye (sodium hydroxide).

Lowering the Amount of FC Needed

There are ways to lower the FC requirement of 7.5% of CYA. Anything that oxidizes or kills will lower the requirement. You could use a SWG (salt water chlorine generator) which replaces buying chlorine. Or you could use a supplemental device such as an ozonator, a UV sterilizer, a mineral purifier or a copper or silver ionizer. You could also add chemicals such as algaecides, phosphate removers, non-chlorine shock or oxidizers or enzymes. Depending on the supplements that are used, the required FC could be lowered to perhaps 2% of the CYA level. With a SWG, the FC recommended is 5% of CYA.

Testing Is Important

It should be clear that it is important to have accurate tests for pH, free chlorine and cyanuric acid. You must know that you have enough free chlorine (technically 0.05 ppm HOCl) to prevent algae growth. You can only know the proper amount of free chlorine if you know the cyanuric acid level and the pH.

Final thoughts

Clearly keeping a free chlorine level of 2.0 to 4.0 ppm may or may not keep algae and bacteria from growing because it depends on the CYA level and the pH. With the information in this article you will be better able to manage the disinfection level in a pool to prevent algae and bacteria growth. Now you have a way to know how much chlorine you need in any pool. It's not the same for every pool.