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Pool Water Testing: Devices and Methods

INTRO TO POOL CHEMISTRY

For a chemical to be used for disinfection the chemical must impart a residual into the pool water and that residual must be measurable. Chlorine continues to be the approved primary disinfectant for swimming pools for this reason. When chlorine is first added to pool water, it takes the form of free chlorine. Upon introduction of contaminants to the pool, chlorine reacts quickly to sanitize and disinfect. This reaction uses up free chlorine and more chlorine must be added to maintain the same level of disinfection.

Proper water chemistry management is important to maintain a safe healthy pool environment for patrons. Several testing kits are available that work based on different chemistry aspects. Despite the reported accuracy and precision of certain tests, a group of people can perform the same test at the same time and find variable results. This creates a great deal of anxiety for pool owners.

For guidelines on proper chemistry management, local regulations often have sections dedicated to water testing. For example, the Pennsylvania state code mandates that "testing kits shall be provided for making the necessary tests for residual disinfection and pH." The state code also references the required accuracy of the measurements for chlorine within 0.1 mg/L and for pH within 0.2 pH. Commercial pools also require more frequent testing compared to residential pools due to the larger variance in pool conditions due to bather load. For Pennsylvania, a minimum of two tests must be completed each day the pool is in use.

This paper will include a description of pool water testing basics, a comparison of chemical test equipment, and a review of appropriate sampling techniques.

FREQUENTLY USED TERMS

Chlorine (Free, Combined, Total)
Chlorine is the common disinfectant for swimming pools. Free chlorine is the form of chlorine available to sanitize and oxidize the water. Combined chlorine is the result of used up free chlorine when it reacts with contaminants. Total chlorine is the sum of the free chlorine and combined chlorine.

Cyanuric Acid (CYA)
Chemical used mostly in outdoor pools as a stabilizer for free chlorine. It prevents the degradation of chlorine by ultraviolet light.

Ppm
Abbreviation for parts per million, a common measure of the concentration of a substance in solution. Assume 1ppm= 1mg/L.

pH
pH is a measure of the acidity or basicity of a solution. pH ranges from 0-14 with a pH~7 as neutral. pH greater than 7 is characterized as basic (alkaline) and pH less than 7 is acidic.

ORP
ORP or oxidation-reduction potential is a measure of the tendency of a solution to gain or lose electrons when encountering another chemical. A properly treated and balanced pool should have an ORP of atleast 700 millivolts.

Alkalinity
Alkalinity is a measure of the buffering ability of water to changes in pH. Higher alkalinity means the water is more resistant to changes in pH.

Hardness
A parameter of water that measures the quantity of scale-forming ions in solution. Total hardness is the sum of calcium and magnesium ions whereas calcium hardness refers only to calcium ions.

Total Dissolved Solids (TDS)
A measure of all solids dissolved in water. TDS includes salt in the case of salt-water pools.

Drop Tests
This refers to any of the tests requiring liquid reagents to measure parameters (e.g. OTO, DPD, DPD-FAS)

Colorimetric Tests
A test method where a reagent reacts with a specific analyte in the sample to produce a color in proportion to the concentration of the analyte (e.g. strips, OTO, DPD)

Titration
A chemical assay done by adding drops to a solution to reach an end-point. The end-point is visualized by a change in color or a change from color to colorless. The number of drops to reach end-point is multiplied by a given factor to acquire the measurement.

Reagents
Solutions or compounds used with testing equipment as chemical indicators to provide measurement of certain parameters.

OTO (or OT)
Abbreviation for the chemical reagent orthotolidine originally used for determining chlorine levels. OTO can only measure the total chlorine level and turns the pool water yellow upon addition.

DPD
Abbreviation for the chemical reagent N, N-diethyl-p-phenylenediamine that is used in drop tests to determine both total and free chlorine levels. The pool water sample turns pink upon addition of DPD.

DPD-FAS
This term refers to a variation of a DPD test that uses titration to determine the measure of free and combined chlorine down to 0.2ppm. FAS, ferrous ammonium sulfate, is the reagent added by titration until the solution changes from pink to colorless signaling the endpoint of the reaction.

Phenol Red
The most common reagent used to determine pH, phenol red works on a range from 6.8-8.2.

Photometer
A portable electronic device used to measure light intensity of a solution. A colorimeter is a type of photometer that limits the wavelength range to 400-700 nm.

Amperometer
A handheld or wired device used to detect ions in solution based on changes in electric current.

BASICS OF POOL CHEMISTRY MAINTENANCE

Maintaining a disinfectant residual in the pool is the main goal of any sanitation plan of the pool facility. However, attaining a suitable chemistry balance for the pool water is equally important. Whereas an appropriate chlorine level will provide a safe environment, a chemically balanced pool will provide a comfortable environment while reducing incidence of scale, corrosion, and other negative effects of unbalanced water. Water balance depends on the following factors: pH, hardness, alkalinity, and total dissolved solids.

The Langelier Saturation Index (LSI) is one way to determine water balance. It is an equilibrium model of the saturation of water with respect to calcium carbonate. The equation factors in calcium hardness, total alkalinity, pH, and temperature to determine this water balance. The pool manager can use the parameters measured from test results to determine the tendency of scaling in the pool. The test results can also be compared to the pre-determined ideal levels available through the NSPF (National Swimming Pool Foundation). The below chart from the Certified Pool Operator (CPO) handbook contains this pool chemistry information. (Table 1.)

The test results of the chemical test kit are compared against these ideal levels and corrective actions are taken depending on the differences between the measured and ideal values. The amount of a specific chemical to add depends on this difference. A summary of corrective actions is found in Table 2. One note to consider is the water quality of the fill water. Most fill water contains minerals and even a moderate amount of chloramines for disinfection of drinking water.Multiple tools to calculate the quantity of chemicals to add are available with little operator time. An example of one of these is the online pool chemistry calculator at www.poolcalculator.com. When the size of the pool and the test data is added, it calculates the quantity of each chemical to add to balance the pool chemistry. Free iphone apps are also available that do the same and may also have a feature to log pool data.

Table 1. Commonly accepted chemical parameters for pool maintenance. (CPO Handbook 2005)

Parameter	Minimum	Ideal	Maximum	Who
Free Chlorine, ppm	1.0	2.0 - 4.0	5.0	Pools, Waterparks
	2.0	3.0 - 5.0	10.0	Spas
Combined Chlorine, ppm	0	0	0.2	Pools, Waterparks
	0	0	0.5	Spas
Total Bromine, ppm	2.0	4.0 - 6.0	10.0	All types
PHMB, ppm	30	30 - 50	50	All types
pH	7.2	7.4 - 7.6	7.8	All types
Total Alkalinity, ppm	60	80 - 100* / 100 - 120**	180	All types
Total Dissolved Solids, ppm	NA	NA	1,500 over start-up	All types
Calcium Hardness, ppm as $CaCO_3$	150	200 - 400	1,000	Pools, Waterparks
	100	150 - 250	800	Spas
Heavy Metals	None	None	None	All types
Visible Algae	None	None	None	All types
Bacteria	None	None	Local Code	All types
Cyanuric Acid, ppm	0	30 - 50	***	All types
Temperature ˚F	78˚F	80.5˚F	82˚F	Competition Pools
	-	Personal Preference	104˚F	Other Pools
	-	-	104˚F	Spas
Ozone, ppm	-	-	0.1 over 8-hour time wtd. avg.	All types
ORP	Calibrate to Disinfectant Level****			All types

† These commonly accepted chemical parameters do not supercede product label directions or local or state codes and regulations.
* For calcium hypochlorite, lithium hypochlorite or sodium hypochlorite.
** For sodium dichlor, trichlor, chlorine gas, BCDMH.
*** Dictated by state or local codes. Typically 100 ppm. (Some codes are higher, some are lower).
**** Some state or local codes may dictate a minimum and maximum.

Table 2. Corrective actions to restore water balance.

Parameter	High	Low
Free Chlorine	None	Add chlorine
pH	Add soda ash	Add muriatic acid
Total Alkalinity	Lower pH to 7.0-7.2 then aerate to increase pH	Add baking soda
Calcium Hardness	Dilution with fresh water	Add calcium chloride
Cyanuric Acid (Stabilizer)	Dilution with fresh water	Add cyanuric acid
Total Dissolved Solids	Dilution with fresh water	N/A

As a general rule of operation, the certified pool operator handbook recommends shocking the pool when the combined chlorine level exceeds 0.5ppm. The commonly used rule for super-chlorination is to add free chlorine in the amount of 10 times the combined chlorine level. For example, if the combined chlorine level is 0.5ppm, the equivalent amount of free chlorine to result in 5ppm of free chlorine is added.

CHEMICAL TEST KIT TYPES

Test Strips

Test strips are the cheapest option for qualitative pool water chemistry testing. Each strip contains one or more indicator-impregnated test pads for each test. A quick dip and color comparison is all that is required for a quick result.

Several issues affecting reliability include storage concerns, strip aging, and sampling errors. Hand-held digital strip readers (~$50) can improve the color comparing aspect yet errors with test strip sampling are not eliminated.

Figure 1. Image of AquaChek 7 test strips and AquaChek TruTest® digital strip reader. (www.aquachek.com)

Basic Test Kits - Drops

Basic test kits use DPD-drop reagents for pool water testing. The test kit typically includes sample vials, a color chart, color wheel, or color comparator, and manufacturer directions. The DPD reagent is often packaged with phenol red reagent for pH as well as other reagents for hardness and alkalinity. An example of this kit is Taylor's K-2005 High DPD test kit. The estimated cost of this kit is $40-50.

Figure 2. Image of Taylor K-2005C service kit. The kit includes DPD testing, turbidimetry, and pH. (http://www.taylortechnologies.com)

Drawbacks of the basic test kit using color comparison include:

- Poor accuracy +/- 0.5 ppm
- Decreasing reliability above 5ppm
- Do not work above chlorine levels of 10ppm (at this level, the test may bleach out and may give the false reading that no chlorine is present)

One improvement to the basic kit is to include DPD-FAS titration. These kits more accurately determine chlorine levels by including the FAS reagent bottle. As with the basic kit, a pink color change indicates the total chlorine in the sample. Then, FAS is added to the sample drop-wise until the sample changes from pink to clear. FAS binds the free chlorine and leaves combined chlorine.

By counting drops, this test offers more precision up to +/- 0.2ppm and is reliable from 0.2 to 20ppm total chlorine. Reader error is also reduced as an absence of color is more discernable than comparing subtle shades of color. However, titration tests take more time (~15-20 min) and higher operator skill to perform. There is a higher incidence of user error that can skew results and make repeatability difficult.

The DPD-FAS can be purchased as a stand-alone kit for about $20 but typically it is provided as part of another kit that also contains reagents to measure hardness, alkalinity, and pH. The complete kits cost about $60-100.

Figure 3. Image of Lamotte's ColorQ Pro 7 colorimeter test kit. (http://lamotte.com)

Spectrophotometry

Spectrophotometry is the quantitative measurement of the reflection or transmission of a material as a function of wavelength. In pool testing terms, these are electrical devices that do the color comparing for the operator. What was previously only available in a chemistry lab is now available in a more portable, more reliable pool-side device known as a Photometer.

Photometers provide precise results of colorimetric tests thus eliminating most of the operator error. As with similar electronic devices, these meters may require regular re-calibration with a factory provided solution. Fouling of the vial or chamber can also skew results and so special care must be taken to avoid scratches while cleaning after each use.

This pool testing method appears to be the most reliable option short of more advanced lab testing that can cost more than $1,000. Boasting very good precision of atleast +/- 0.1 ppm on free chlorine and +/- 0.1 pH units, these units cost about $150-300 and are able to measure multiple parameters.

Figure 4. Image of new eXact iDip photometer testing. (http://www.sensafe.com)

One example is Lamotte's ColorQ Pro 7 (Figure 3) that reads seven test parameters on a digital display. This meter uses a sample vial and liquid reagent drops similar to the basic test kit to perform the test. Other models are available from Lamotte that instead use TesTabs, solid reagent tabs, instead of drops.

Sensafe photometers (Figure 4) use reagent strips similar to test strips that deliver a controlled quantity of reagent. Doubling as a mixer, the reagent strip is single use for a certain parameter. These meters also feature a built-in chamber and waterproof design such that the sample is loaded directly to the meter by dipping the device into the pool.

Figure 5. Image of Hanna Instruments HI98121 Combination pH and ORP Meter. (http://www.hannainst.com)

Amperometry

Amperometry is the detection of ions in a solution based on changes in electric current. In the pool testing world, amperometers can be seen as single hand-held devices or as part of a continuous monitoring system. Typically, each probe can only measure one parameter at a time.

ORP meters measure the difference in electrical potential between a reference and the pool water. The reading displayed on the meter is the difference in potential between positive and reference electrodes.

Generally, ORP meters can relate the effectiveness of the oxidizer, free chlorine. However, other factors have an effect on the degree of ORP that makes this answer less precise. As the pH increases in a chlorine pool, the oxidation reduction potential decreases since there is less hypochlorous acid in the pool. For this reason, ORP meters are often coupled with a pH probe. Other chemicals in the pool can also skew an ORP reading including chloramines.

Amperometers are simpler to use and operate than other test methods. There are no reagents to add and no counting of drops. The probe is inserted into the sample and allowed to stabilize to provide a reading. This stabilization time can be as long as 10-12 minutes. Some probes may require priming with solution to reduce the time it takes to get a stable reading. Cleaning of the probe after each use and proper storage is important to maintain a reliable testing device. Manufacturers' often provide solutions with known pH for calibration of the pH probe however the ORP probe is generally factory calibrated.

The cost for the meter is comparable to other photometers. The approximate cost of one of these meters that include both ORP and pH is about $200-300. An example is the Hanna Instruments HI 98121 Combination pH and ORP tester. This unit has a removable pH electrode for easy replacement and also comes with a 6 month warranty. The unit has an accuracy of +/- 0.05 pH and +/- 2 mV. Calibration of the pH is required every month of use. After the warranty period, it may be easier and more cost-effective to simply buy new rather than repair.

SAMPLING TECHNIQUE

Sampling technique and especially operator error is often the greatest obstacle to achieving accurate repeatable results. Reading the manufacturers instructions for the specific equipment used is of the utmost importance. While it can be expected that different testing methods have different instructions for proper testing, it cannot be assumed that similar test kits from different manufacturers will have the same instructions.

Here are general tips to follow when water testing as follows:

Sample

For consistency, it is recommended that a representative sample be collected first prior to testing. Representative means that the sample is taken from an area of the pool that is well-mixed. To collect the sample, use the following guidelines:

- Use a clean sample bottle that is large enough to produce 2-3 times the water necessary to perform the test. A bottle that is closeable is preferred. Glass is recommended over plastic since the plastic has chlorine demand.
- Rinse the bottle three times with the pool water.
- Choose a location that is away from chemical injection inlets or the shallow end. A location that is midway between shallow and deep ends of the pool is preferable.
- Insert the bottle upside down into the water atleast two feet down below the water surface.
- Invert the bottle to fill it with the sample.
- Remove the bottle from the water and quickly cap it unless the water is tested immediately.

Storage

Reagents will naturally degrade over time as they are exposed to the environment. Since they cannot feasibly be stored in a vacuum, certain considerations need to be realized to get the most out of the chemical's limited shelf-life.

- Store reagents at a consistent temperature in the range from 36-85°F. Avoid extremes such as storing them in a car or refridgerator.
- Keep reagent bottles tightly capped to protect against moisture and other contaminants. Replace defective or broken caps immediately.
- Keep reagents separate from pool chemicals as much as possible.
- Keep reagents out of direct sunlight as the sunrays may degrade certain light-sensitive reagents.

Dilution

Where applicable, it may be possible to read levels above the limit of the test employed. Dilution is one method to continue in this case without having to change testing methods. There are some specific tips regarding dilution however:

- Always dilute the sample before adding the reagent.
- Use only distilled water to dilute the sample not tap water.
- Always fill to the fill line on the test vial. If doing a 2x dilution, fill half with pool water sample then fill to line with deionized water.
- Understand that with dilution will sacrifice some accuracy. As a rule of thumb, multiply the resolution by the dilution factor as well to get the new precision of the test.

Here are other kit-specific tips that are useful knowledge for testing:

Strips:

- Prior to testing, limit exposure of the strip to air. Keep the strip container tightly sealed.
- Collect a representative pool water sample in a sample vial. Then use the strip on this sample rather than dipping directly into the pool.
- After dipping, hold the strip horizontal with respect to the ground so that chemicals do not run between pads.
- Allow the correct amount of time to pass before reading the strips.

Liquid Kits:

- Keep the reagent bottles tightly capped when not in use
- Always hold the dropper bottle vertical when administering drops. Holding the bottle on a diagonal will “kip” the drops resulting in smaller drops and will skew results.
- Use a damp cloth to clean the tip of the dropper bottle. Over time, static may build on the tip resulting in smaller or inconsistent drops. Removing this static will make drop size more consistent.

Portable Electronic Instruments:

- These instruments require more care and maintenance to extend life and should be calibrated regularly against reliable standards.
- Do not allow probes to dry in storage. Probe should be stored wet with the solution provided by the manufacturer and not with deionized nor distilled water.
- Limit the performance of the calibration task to only one operator.
- After each use, cleaning of the instrument is required to keep it in working order for the next test.
- Follow additional guidelines by the manufacturer for handling and use to optimize the life of the unit.

CONCLUSION

Several factors need to be considered when purchasing a pool water quality testing device. These should include primarily the cost per test and types of tests required and also the reliability, accuracy, and durability of the selected test. Local codes often set limits for minimum accuracy of pool tests. This paper provides a survey of the testing available. By attaining a grasp of pool water chemistry and understanding the various testing methods, a cost-effective testing regimen can be better developed to meet local regulations.

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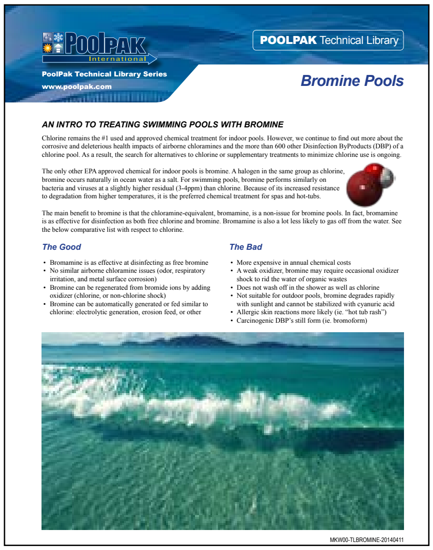
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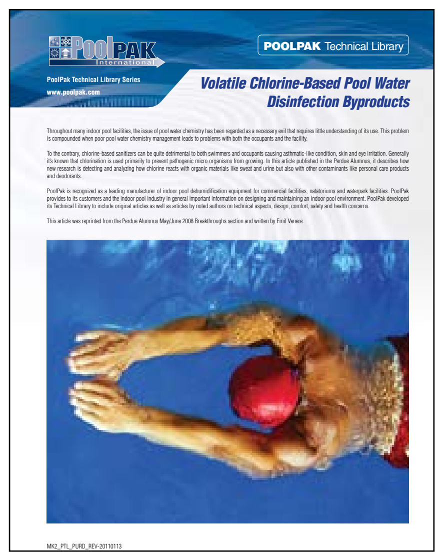
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