



Foreword

Changes to pool surfaces are not necessarily attributable to material or manufacturing defects. They are often associated with water quality, operating conditions, the care and treatment of the pool water, as well as the interactions between water chemistry and the materials used.

This guide explains the fundamental principles and key interrelationships of water chemistry in swimming pool operation. It provides a practical understanding of how water quality, water treatment, operating conditions and material behaviour interact, and which mechanisms can lead to surface changes, deposits or other operating-related phenomena.

The guide is intended in particular for specialist **retailers, specialist planners, swimming pool builders, service technicians and other professionals** involved in the planning, installation, commissioning, servicing and maintenance of swimming pool systems. It is also intended to provide technically interested readers with a sound basis for understanding the relevant interrelationships.

The aim is to support the professional assessment of water quality and operating conditions, to identify possible causes of changes at an early stage, and to promote the appropriate and material-compatible operation of swimming pools.

Disclaimer

This guide does not claim to be complete and does not constitute either a binding guideline or a generally recognised rule of technology. In particular, it does not replace compliance with applicable legislation, standards, manufacturer specifications or product-specific operating instructions.

The contents have been prepared to the best of our knowledge and with the greatest possible care. They are based on the professional knowledge available at the respective date of the document. No guarantee can be given for the completeness, accuracy or currency of the information provided.

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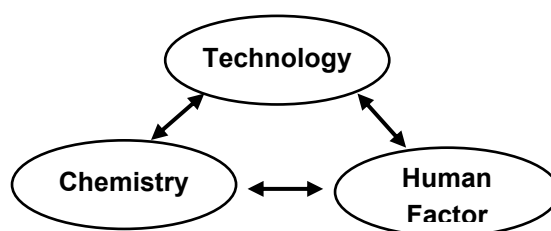
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1. Objective and Fundamental Understanding

The objective of a swimming pool is not merely to maintain clear water, but to ensure a consistently hygienic and material-friendly operation in accordance with **EN 16713-3**.

Achieving this requires the proper interaction of technology, water chemistry, and correct operational practices. This understanding is important not only for fiberglass-reinforced plastic (FRP/GRP) pools, but for all pool surface materials, including concrete, stainless steel, polypropylene (PP), PVC, natural stone, liners, and tiles. Water chemistry and operational management affect not only hygiene but also the pool surfaces themselves and adjacent construction components. Discoloration, deposits, bleaching, loss of gloss, or material damage may result from both chemical influences and operational factors.

2. Water Quality as the Result of Technology, Water Chemistry, and Operator Responsibility



A consistently high level of water quality is achieved through the interaction of pool technology, water treatment chemistry, and regular operational supervision. Pool technology includes, in particular, reliable water circulation, effective filtration, and stable dosing systems. Water chemistry ensures that organic contaminants are oxidized, microorganisms are inactivated, and both the pH value and buffering capacity are maintained within the appropriate range. The operator is responsible for understanding the system, regularly verifying measurement data for plausibility, recognizing abnormalities, and taking corrective action in a timely manner.

To maintain consistently high hygienic water quality, automated disinfection systems equipped with suitable monitoring and control technology have proven effective. These systems enable demand-based chemical dosing while reducing manual intervention and the associated fluctuations in water quality.

Key Water Parameters for Pool Operation:

- **Control Parameters:** pH value, free chlorine / oxidation-reduction potential (ORP/Redox potential)
- **Influencing Parameters:** Water temperature, Total alkalinity (TA) / carbonate alkalinity, Cyanuric acid
- **Quality Indicators:** Chloride, Combined chlorine, Calcium hardness, Phosphate
- **Aggregate Parameters:** Conductivity / TDS (e.g. chloride, sulfate, sodium, calcium, magnesium, TA)

Extract of Typical Treatment Chemicals Used in Monitoring, Control, and Dosing Systems:

- **Disinfection:** Chlorine (see also EN 16713-3)
- **pH-Reduction (-):** Sulfuric acid (according to EN 15078), CO₂ (according to EN 15513)
- **pH-Increase (+):** Sodium hydrogen carbonate (EN 15075), sodium carbonate (EN 15362)
- **Coagulation / Flocculation** (e.g. according to EN 15031 or EN 15797)

It is essential that disinfection systems, and in particular the values displayed by their monitoring equipment, are regularly verified for plausibility through manual testing, at least once per week. This is the only reliable way to detect measurement drift, control errors, unnecessary chemical consumption, and potential consequential damage at an early stage. A stable, demand-based disinfection level is required to ensure hygienic safety while avoiding unnecessary stress on pool materials and equipment.

Note: Chlorine does not only act against microorganisms in pool water but also helps control algae. It damages the cellular structure of algae, thereby inhibiting their growth and reproduction. However, this protective effect is limited and depends on several factors, including the chlorine concentration and the pH value of the water.

Primary Chlorine Disinfectants According to EN 16713-3 (for Automated Disinfection Systems):

Chlorine Gas

- Compressed gas cylinders (restricted to public swimming pools due to the high hazard potential)
- In situ electrolysis (membrane cell / closed) from pure NaCl solution

Sodium Hypochlorite

- Sodium hypochlorite solution (12–15%) supplied in containers, in accordance with EN 15077
- In situ electrolysis (pipe cell) from pure NaCl solution into an intermediate tank (anolyte)
- In-situ inline electrolysis (open pipe cell) using salt-enriched pool water filtrate

The following section provides a comparison of the different chlorine disinfection systems:

Note: The information provided is intended as a qualitative, general guide to the typical characteristics of different systems and may vary considerably depending on the specific system design, sizing, operating conditions, manufacturer, and installation.

	a) Cl ₂ (pressurized cylinder)	b) Cl ₂ (In situ electrolysis)	c) NaClO (Liquid, EN 15077)	d) NaClO-Anolyt (In situ electrolysis)	e) NaClO-Anolyt (In situ inline electrolysis)
Process stability	High	High	High	High	Medium
Side reactions	pH↓	pH↓	pH↑	pH↑	CO ₂ ↓/pH↑
Hazard potential	High	Low	Low	Low	Low
Maintenance effort	High	High	Low	Low	Low
Costs (operation)	Medium	High	Low	Low	Low
Costs (investment)	Medium	High	Low	Medium	Low

This means that for chlorination systems, regular pH monitoring and—depending on the disinfection method and operating conditions—an appropriate pH control system are always recommended.

Generally, it should be noted that dissolved substances and disinfection by-products accumulate in pool water as a result of bathing activity, water treatment, and disinfection, and can only be limited through dilution with fresh water. In many private swimming pools, a regular partial water replacement of approximately 2–3% per week has proven to be effective. The German Environment Agency (UBA) generally refers to the need for fresh-water replenishment in order to prevent the undesirable accumulation of substances that cannot be removed. Chlorate, for example, cannot be degraded in pool water and can only be reduced by dilution [9].

Notes on e) In-Situ Inline Electrolysis Systems with Open Pipe Cells:

For in-situ inline electrolysis systems with open pipe cells, it should be noted that, in addition to the increased chloride load, hydrogen is generated during the electrochlorination process. Typical systems can produce several thousand litres of hydrogen per day, which is why safe venting and/or monitoring is required [3].

From an operational perspective, it should also be noted that this type of saltwater electrolysis system promotes an increase in pH to a greater extent than other chlorination methods. This is caused by electrochemical processes at the cathode as well as enhanced CO₂ stripping.

The effectiveness of disinfection and the formation of undesirable by-products depend strongly on the operating conditions at the site, in particular on the pH value, water composition, purity of the chemicals used, proper functioning and maintenance of the measuring electrodes, and the pool care products used. Deviations from the intended operating conditions may result in the formation of undesirable by-products [1] as well as fluctuations in chlorination and pH.

According to the current state of scientific knowledge, there is no robust evidence that the salt concentration typically found in private “saltwater pools” has a therapeutic effect on the skin.

Bromide-containing products or contaminated salts must not be used, as otherwise bromate, which is considered a substance of health concern, may be formed ([1], [2], [4]). The relevance of this issue is also demonstrated by the fact that the European Standard EN 16370 explicitly limits the permissible bromide content of the sodium chloride used in such systems [4].

This process requires regular monitoring of operating parameters to ensure proper operation and quality assurance. However, in private applications, the same analytical quality control capabilities as those available for the industrial production and quality assurance of chlorine products are generally not available.

3. Alkalinity and pH Value

Alkalinity and pH are of central importance for pool operation. The pH value influences not only the effectiveness of disinfection, but also the tendency for scale formation, corrosion, loss of gloss, and surface alterations. Alkalinity, usually expressed as Total Alkalinity (TA) or acid-neutralizing capacity, acts as a buffer and stabilizes the pH value. It indicates the amount of acid required to adjust a defined volume of water to pH 4.3. If alkalinity is too low, the system becomes sensitive and the pH value can fluctuate rapidly. If it is too high, pH control becomes more difficult and the consumption of control chemicals increases.

Total alkalinity is primarily determined by carbonate alkalinity. Cyanurates (CYA), borates, and phosphates generally play a secondary role. It is important to distinguish between **carbonate alkalinity** and **carbonate hardness**. In practice, these terms are often confused, although they do not mean the same thing. Carbonate alkalinity is the key factor governing pH stability and CO₂ buffering, whereas carbonate hardness describes the proportion of dissolved calcium and magnesium ions associated with carbonate alkalinity. This distinction is important for operational assessment, as scaling tendencies and pH behaviour can only be reliably evaluated with a correct understanding of water chemistry.

- **Carbonate alkalinity [mg/l CaCO₃] ≈ TA [mg/l CaCO₃] – (CYA [mg/l] / 3)**
- Carbonate hardness KH [°dH] = Minimum(total hardness, carbonate alkalinity)
- Total hardness = Total concentration of dissolved calcium and magnesium ions

In practice, a simplified approach is often used:

- **KH [°dH] ≈ TA [mg/l CaCO₃] / 17,85**

In softened water, carbonate alkalinity may be high while carbonate hardness (KH) remains low, because calcium and magnesium ions have been replaced by sodium ions.

Insufficient carbonate alkalinity can result in unstable pH conditions, an increased tendency toward corrosion, reduced flocculation efficiency, and unreliable measurement values. Measuring sensors may also age more rapidly or provide implausible readings. For this reason, regular monitoring of total alkalinity (TA) is an important part of routine pool operation.

In photometric pH measurement using Phenol Red tablets, reagents (typically thiosulfate) are generally used to reduce the influence of chlorine on the measurement result. However, according to manufacturers' specifications, very low TA values (< 35 mg/L as CaCO₃) may still lead to incorrect pH readings.

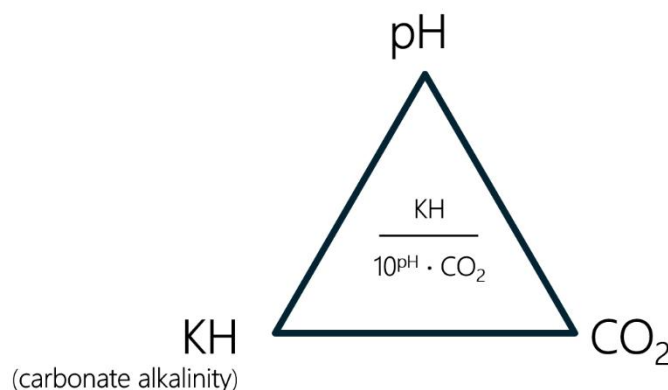
4. Carbonate–CO₂ Equilibrium and pH Control

The pH value in pool water is closely related to the carbonate–CO₂ equilibrium. Carbon dioxide is dissolved in the water but can escape into the surrounding air. This loss of CO₂ causes the pH value to rise. The level of carbonate alkalinity influences the stability of the system: with high buffering capacity, the pH value often appears more stable, but the effort required for pH control increases. If the buffering capacity is too low, there is a risk of a rapid drop in pH, potentially resulting in an acid crash.

Different methods are used in practice for pH reduction. Acid dosing is technically simple but can reduce carbonate alkalinity and may lead to a less stable system over the long term. It also increases the dissolved salt content of the water, for example through sulfate accumulation. CO₂-based pH control can offer advantages in this regard, as it does not consume carbonate alkalinity and therefore allows for more stable operation.

It is important to understand that pool water is always governed by a dynamic equilibrium between dissolved CO₂, bicarbonate, and carbonate. When the CO₂ concentration decreases due to outgassing, the pH value rises. When CO₂ is deliberately added, the pH value decreases again without consuming buffering capacity to the same extent as mineral acids.

This relationship is illustrated in the following triangle diagram. It demonstrates that these three parameters are interdependent, since under practical pool-water conditions (assuming no significant contribution from other buffering systems), the relationship tends toward a constant value of approximately 1/30 ppm [7].



This relationship applies approximately within the pH range of **6 < pH < 9**:

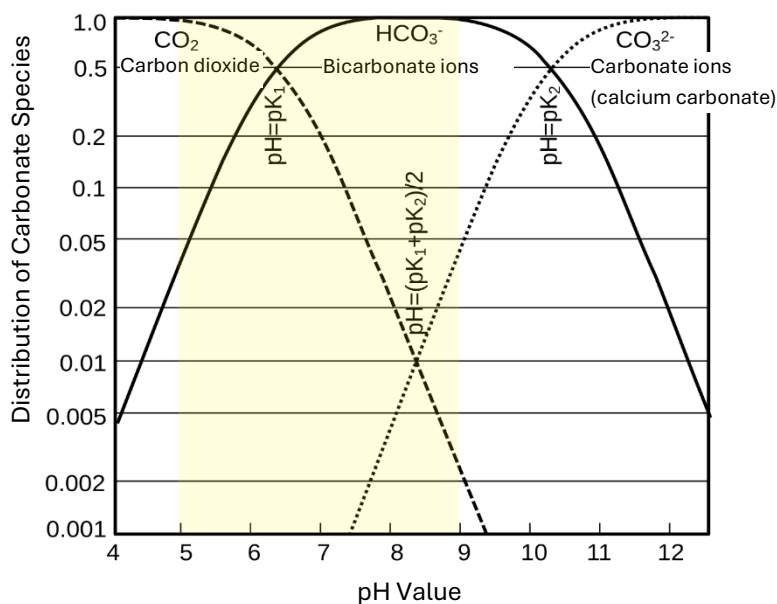
$$\text{CO}_2 \approx \frac{\text{KH}}{2,8} \cdot 10^{7,91 - \text{pH}}$$

Within this pH range, the water exists in a calcium **carbonate-carbonic acid equilibrium**, in which dissolved CO₂, bicarbonate, and calcium carbonate mutually maintain a state of balance. When this equilibrium is balanced, no excess CO₂ is present.

If there is a deficiency of free CO₂, the equilibrium shifts towards carbonate formation. Bicarbonate is converted into carbonate, which can react with calcium ions to form sparingly soluble calcium carbonate (scale). This effect becomes significantly more pronounced as the pH value increases (typically in the alkaline range, pH > 8), since the proportion of carbonate ions increases.

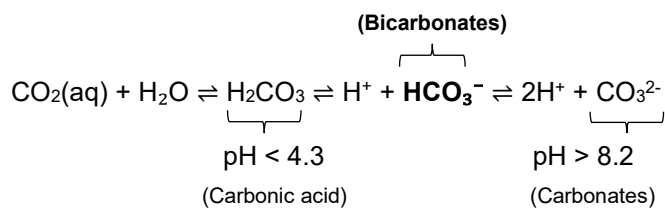
Conversely, an excess of dissolved CO₂ results in a scale-aggressive water condition. In this case, calcium carbonate from existing deposits is dissolved again in order to re-establish chemical equilibrium. The dissolved carbonic acid acts as the equilibrium partner that keeps the carbonate alkalinity in solution.

The actually effective carbonic acid (H₂CO₃) represents only a very small fraction (typically ~0.1%) of the total dissolved CO₂ in the water (CO₂(aq)).

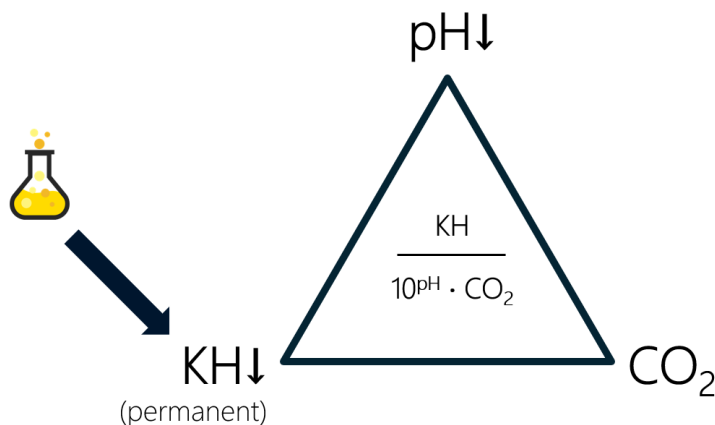
Carbonic Acid–Bicarbonate–Carbonate Equilibrium as a Function of pH


Source: Johannes Kalliauer, <http://www.trinkwasserspezi.de/Image3.gif>, licensed under CC BY-SA 4.0, <https://commons.wikimedia.org/w/index.php?curid=86170265>

The underlying equilibrium is:



pH Reduction Using Acid:



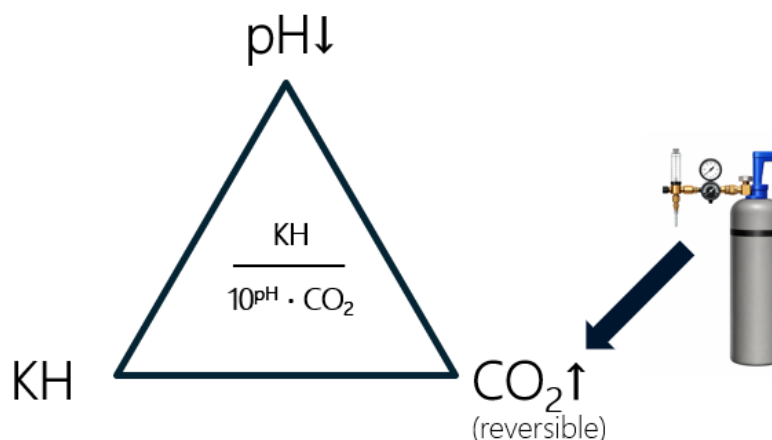
In chlorine-based systems, the pH value is frequently reduced by the addition of sulfuric acid. The acid initially affects primarily the carbonate alkalinity. This creates an excess of dissolved CO_2 , which subsequently outgasses over the following hours and days, causing the pH value to rise again. A container of pH-minus product can also increase the sulfate concentration, which is particularly relevant for concrete surfaces and mineral-based grout joints.



Since the concentration of dissolved CO_2 does not initially change significantly immediately after acid addition, the reduction in carbonate alkalinity results in a relative excess of dissolved CO_2 within the system. This condition shifts the equilibrium towards a lower pH value. Over the course of hours to days, this excess CO_2 gradually escapes into the atmosphere, causing the equilibrium to shift again and the pH value to rise.

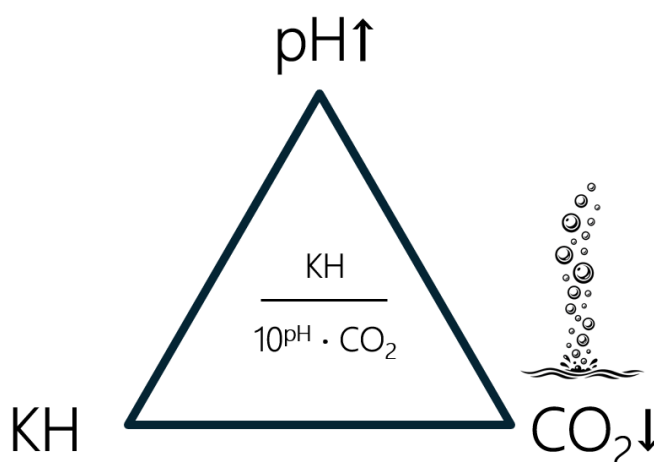
Note: The addition of sulfuric acid (e.g. via a pH-minus product, 20 kg, 14.9%) also leads to an increase in the sulfate concentration of the water. In a 30 m³ pool, this can result in an increase of up to approximately 100 mg/L SO_4^{2-} . This aspect should be considered particularly in concrete pools and in mineral-based grout joints that are in permanent contact with pool water.

pH Reduction Using CO₂ (EN 15513):



In CO₂-based pH control systems, an excess of dissolved carbon dioxide is deliberately introduced into the water (a saturated CO₂ solution has a pH value of approximately 5). This dissolved CO₂ exists in a reversible equilibrium with the carbonate alkalinity and can subsequently be released again through outgassing to the atmosphere.

In contrast to acid dosing, which irreversibly alters the carbonate alkalinity, the system remains largely closed with regard to buffering capacity when CO₂ is used for pH control. As a result, the reduction in pH occurs more slowly and with greater inertia, but is generally more stable.

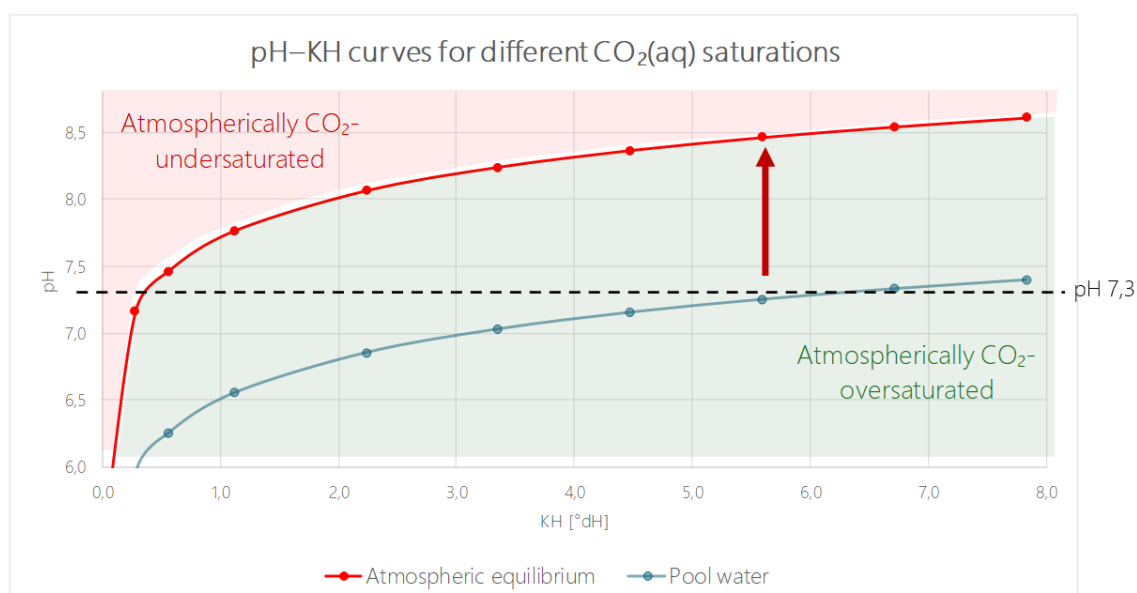


For practical operation, this means that good pH management is not solely a matter of the measuring electrode or the control system, but above all a matter of understanding the overall system. Temperature, water movement, surface contact, pool geometry, pool covers, and air exchange all influence CO₂ release and therefore pH stability. Measurement values must therefore always be evaluated in the context of the actual operating conditions.

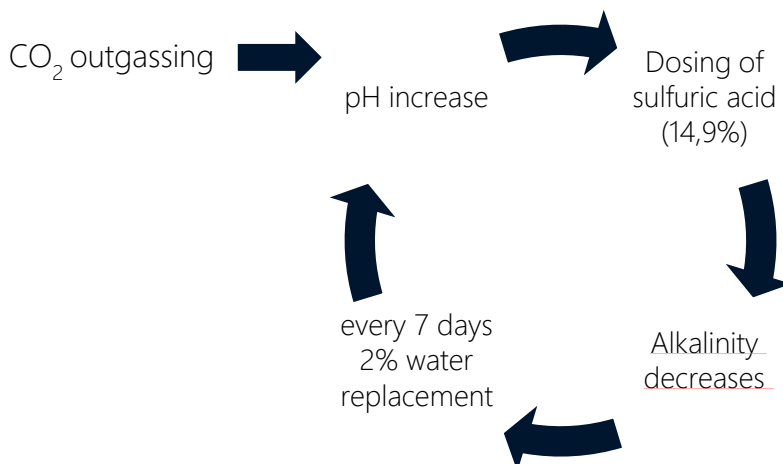
pH Control with Acid Due to CO₂ Outgassing in the Absence of Chlorination

Even without chlorination, the pH value increases as a result of CO₂ outgassing, which is why regular pH control remains necessary. Fresh pool water is generally supersaturated with CO₂ [8]. The rate of CO₂ loss depends, among other factors, on pool covers, water surface area, air movement, water circulation, and temperature. If total alkalinity (TA) is not adequately maintained, alkalinity can decrease to nearly zero, causing the water to become highly pH-unstable. Under such conditions, even small additions of acid may trigger an acid crash.

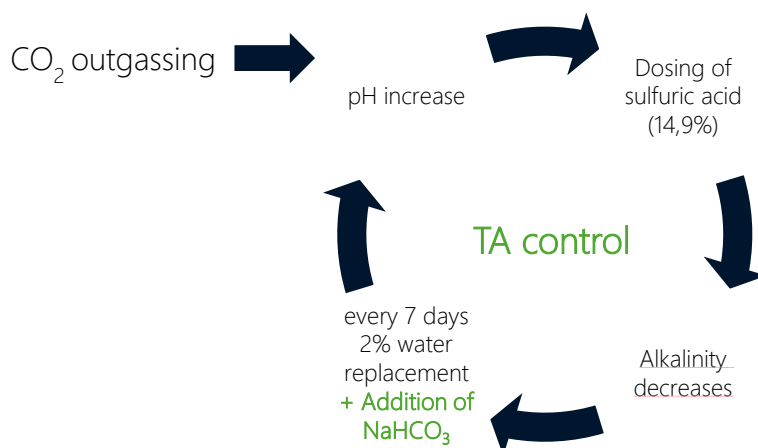
To illustrate this: pool water with a pH value of 7.3 and an alkalinity of TA = 100 mg/L CaCO₃ (approximately 5.6 °dKH) contains about 11 mg/L dissolved CO₂(aq) at equilibrium. Outdoor air typically contains around 450 ppm CO₂, which corresponds to only about 0.67 mg/L dissolved CO₂(aq) in water. Pool water is therefore significantly supersaturated with CO₂ relative to the atmosphere and consequently tends to continuously release CO₂. At an average TA value of approximately 100 mg/L CaCO₃, a pH increase of up to ΔpH ≈ +1.0 per week is fundamentally possible as a result of this process, depending on factors such as pool cover, water surface area, wind, water movement, and temperature.



If, in exceptional cases, the fill water has a very high carbonate alkalinity, part of the alkalinity loss can be compensated to a limited extent by the weekly partial water replacement associated with the required filter backwashing:

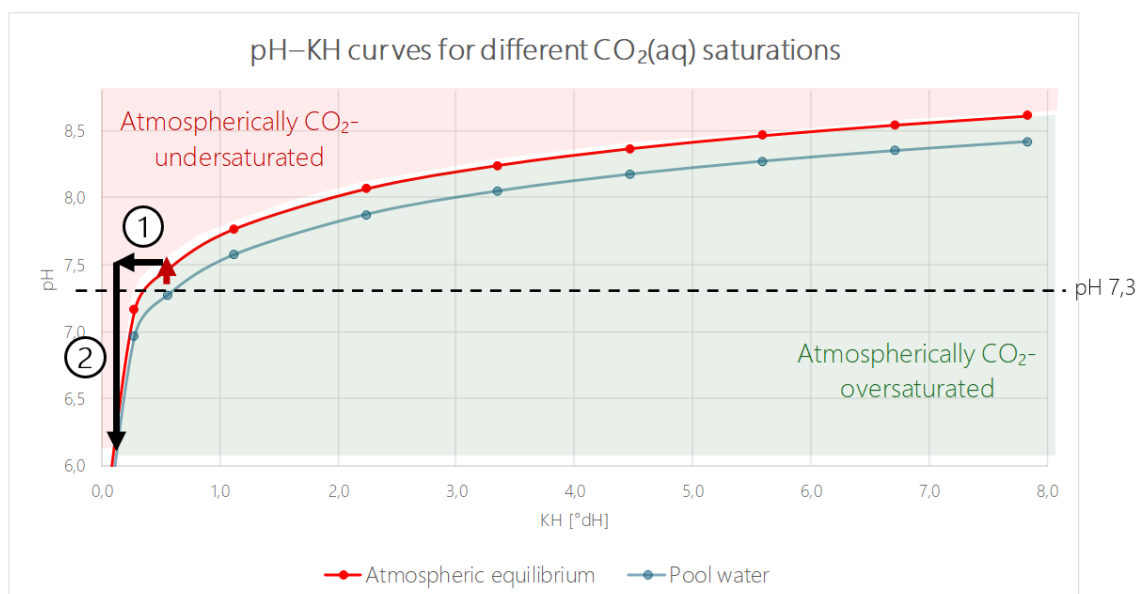


In practice, however, the remaining alkalinity loss usually has to be compensated by the regular addition of sodium bicarbonate (NaHCO₃). It should be noted that the rate of CO₂ loss increases significantly as alkalinity increases:



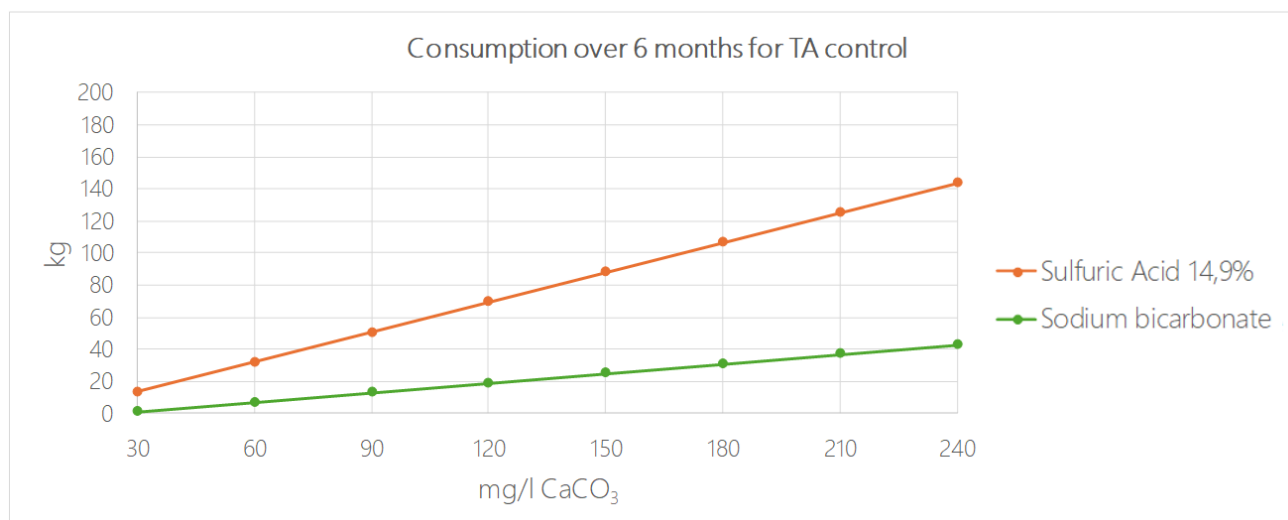
If no regular TA maintenance is carried out, alkalinity can decrease to very low levels, approaching 0 mg/L CaCO₃. In this range, the water becomes highly pH-unstable, so that even small additions of acid can trigger an acid crash.

To illustrate this: pool water with a pH of 7.3 and a very low alkalinity of TA = 10 mg/L CaCO₃ (approximately 0.56 °dKH) contains only about 1 mg/L dissolved CO₂(aq) at equilibrium. Despite this low concentration, the water remains supersaturated with CO₂ relative to the atmosphere and continues to release CO₂, causing the pH value to rise further. An additional addition of, for example, 1.7 L of sulfuric acid (14.9%) to a 30 m³ pool would reduce the carbonate alkalinity by 10 mg/L CaCO₃ (ΔTA = -10 mg/L CaCO₃) and thereby promote an acid crash with pH values below 6:



This demonstrates that a carbonate alkalinity of less than 1 °dKH already results in a significant corrosion risk.

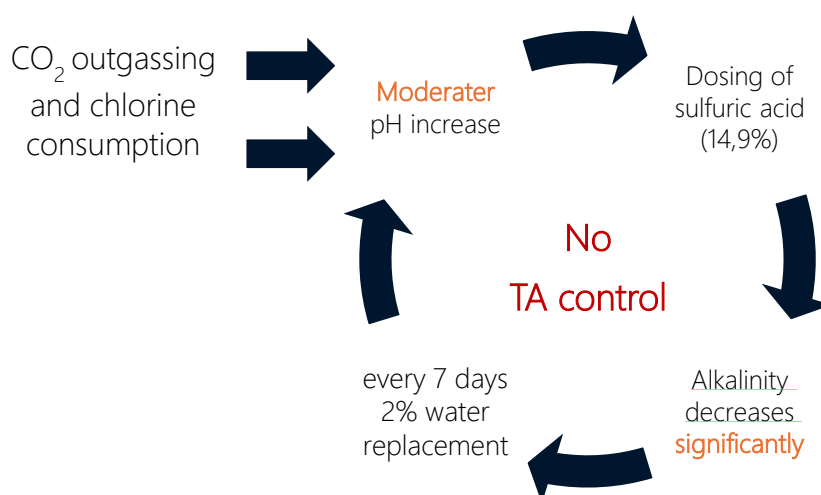
The following chart illustrates the consumption of sodium bicarbonate and sulfuric acid (14.9%) as a function of the target TA level, based on a six-month simulation for a non-chlorinated 30 m³ pool (assumptions: 28°C water temperature, pH maintained at 7.3, fill water with TA = 100 mg/L CaCO₃, average daily bathing load):



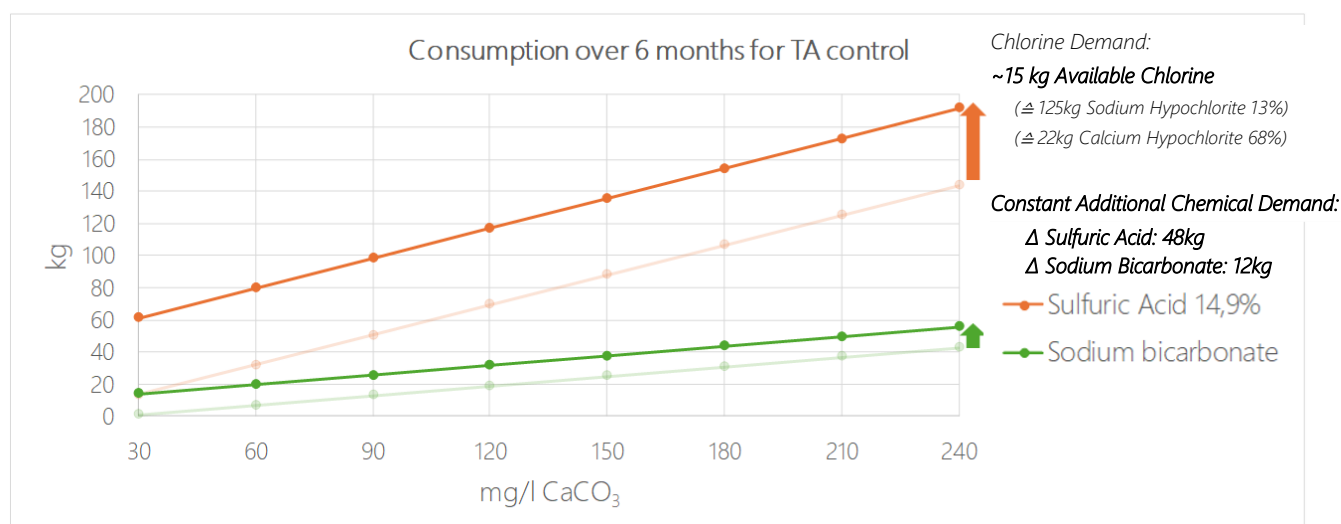
⇒ The simulation model shown demonstrates that the consumption of control chemicals increases unnecessarily as the target TA value rises.

pH Control with Acid Due to CO₂ Outgassing and Chlorination

In chlorinated pools (with inorganic chlorine), chlorination further enhances the increase in pH. Without adequate TA compensation, this often leads to very low TA values within only a few weeks, resulting in pH instability, acid crashes, and corrosion effects, particularly when combined with elevated chloride concentrations.



The following chart shows the consumption of sodium bicarbonate and sulfuric acid (14.9%) as a function of the target TA level. The data are based on a six-month simulation of a chlorinated 30 m³ pool (assumptions: water temperature 28°C, free chlorine 0.4 mg/L, pH maintained at 7.3, fill water TA = 100 mg/L CaCO₃, average daily bathing load):



The simulation model shown demonstrates that the additional consumption of control chemicals resulting from chlorination remains largely independent of the target TA value across the TA range examined in the model.

At the same time, the ratio of the consumption components shifts:

At lower target TA values, consumption resulting from chlorine demand predominates, whereas at higher TA values the influence of CO₂ outgassing becomes increasingly dominant.

In this model, the transition range at which CO_2 outgassing becomes the primary contributor to control chemical consumption is approximately 90 mg/L CaCO_3 .

The appropriate TA range depends on the treatment method used and the operational strategy. As a minimum technical requirement, a value of > 36 mg/L CaCO_3 may be derived from DIN 19643 (among other reasons, to ensure sufficient flocculation efficiency and the establishment of a calcium carbonate-stabilizing equilibrium).

In practice, higher target ranges are often recommended depending on the system design, for example 60–120 mg/L CaCO_3 .

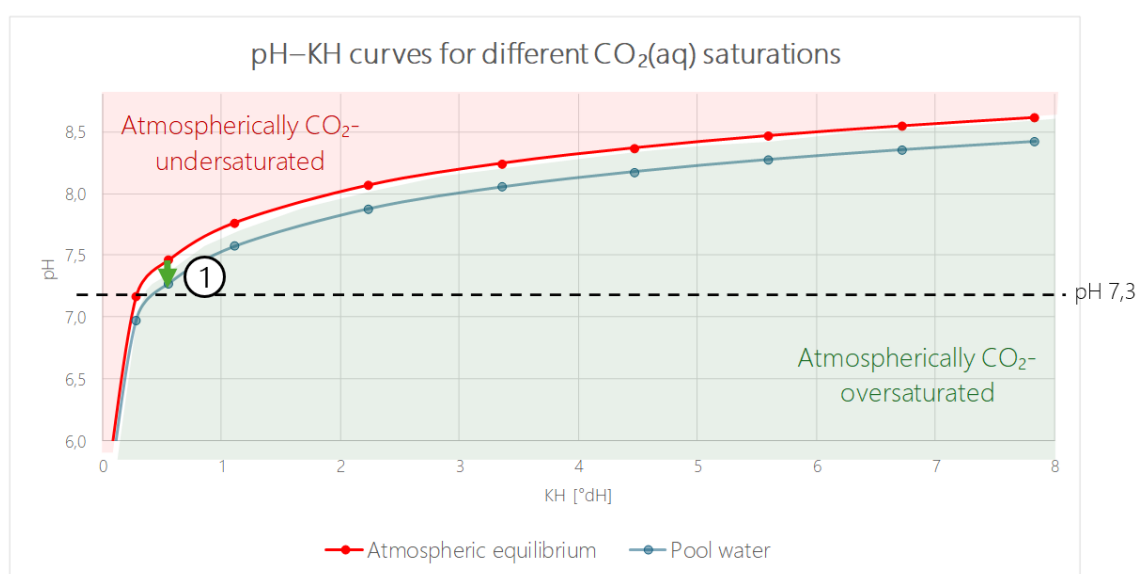
pH Control with CO_2 (EN 15513) Due to CO_2 Outgassing During Chlorination

pH control using CO_2 is a sensible alternative, particularly when a low to moderate TA range is maintained in a controlled manner. CO_2 consumption depends strongly on TA: high TA values increase CO_2 loss through outgassing, whereas lower TA values reduce the demand.

Annual CO_2 consumption is estimated to be up to approximately 4 kg CO_2 per m^3 of pool water at a TA value of around 60 mg/L CaCO_3 (see also [6]). For a 30 m^3 pool, this corresponds to up to 60 kg of CO_2 over a six-month swimming season.

IMPORTANT: When pH is controlled using CO_2 while disinfection is performed with sodium hypochlorite, the carbonate alkalinity of the pool water gradually increases. This is because the hydroxide ions generated during chlorination react with the dosed CO_2 to form bicarbonate, thereby contributing permanently to the water's alkalinity.

A 25 kg container of sodium hypochlorite (12–13% available chlorine) can increase the carbonate alkalinity of a 30 m^3 pool by up to approximately 50 mg/L as CaCO_3 when CO_2 is used for pH control. This corresponds approximately to the alkalinity increase achieved by adding 3.4 kg of sodium bicarbonate (NaHCO_3).



① pH Reduction using CO_2 (0.25–0.5 L/min for a 30 m^3 pool)



Advantages of CO₂-Based pH Control:

- More stable process control (no consumption of alkalinity)
- Lower risk of acid crashes
- Optimized flocculation performance (stable TA)
- Reduced salinity increase (**no sulfate accumulation**)
=> **Of particular importance for concrete pools and tiled pools with mineral-based grout joints**
- Improved plant safety (no risk of acid–hypochlorite mixing)
- Can reduce chlorine consumption.
- Can create favorable conditions for lower disinfection by-product formation.

CO₂ storage must be carried out properly due to the associated safety risks: in a well-ventilated area, protected from heat and direct sunlight, not below ground level, and equipped with appropriate warning signage, a CO₂ gas detector, and measures to prevent cylinders from tipping over.

Special Case:
CO₂ for TA-Control During Sodium Hypochlorite Dosing together with Acid-Based pH Control

When sodium hypochlorite is used for chlorination in combination with targeted CO₂ dosing, the **carbonate alkalinity** of the pool water can gradually increase over time. This is because the hydroxide ions present during chlorination react with the dosed CO₂ to form bicarbonate, thereby contributing permanently to the water's alkalinity.

The underlying chemical processes are as follows:

- Commercial liquid chlorine (sodium hypochlorite, approximately **12–13% available chlorine**) typically contains:
 - **12–13 wt.% sodium hypochlorite (NaOCl)**
 - **10–12 wt.% sodium chloride (NaCl)**, formed as a by-product during the manufacturing process
 - **0.2–0.6 wt.% sodium hydroxide (NaOH)** to stabilize the sodium hypochlorite solution
 - **small amounts of chlorate**, formed as a by-product during manufacturing and as a result of product aging and storage
 - **Balance: water**
- Sodium hypochlorite dissociates immediately in water:
 $\text{NaOCl} \rightarrow \text{Na}^+ + \text{OCl}^-$
- The sodium hydroxide present also dissociates completely:
 $\text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^-$
- The hypochlorite ion is in a pH-dependent equilibrium with hypochlorous acid:
 $\text{OCl}^- + \text{H}_2\text{O} \rightleftharpoons \text{HOCl} + \text{OH}^-$
As the pH increases, the equilibrium shifts progressively towards the hypochlorite ion (OCl⁻).
- The hydroxide ions present in the system are captured by the dosed carbon dioxide and converted into bicarbonate:
 $\text{CO}_2 + \text{OH}^- \rightarrow \text{HCO}_3^-$

As a result, part of the alkalinity provided by chlorination does not manifest itself as a permanent increase in pH but is converted, through reaction with CO₂, into bicarbonate ions, thereby increasing the carbonate alkalinity.

Practical implication: This effect can be utilized deliberately. General pH control is carried out primarily with a mineral acid (e.g., sulfuric acid), while CO₂ is dosed exclusively to compensate for the pH increase caused by sodium hypochlorite (CO₂ dosing only during chlorine dosing, followed by an appropriate post-dosing period). Under suitable operating conditions, this approach can establish a stable and practical level of carbonate alkalinity over the long term. At the same time, acid consumption is slightly reduced. In addition, the need for supplementary sodium bicarbonate to maintain total alkalinity (TA) can be significantly reduced or even eliminated entirely.

Advantages of this Combined Operating Strategy

- More stable process control (partial compensation of alkalinity depletion)
- Reduced risk of acid crash
- Lower consumption of mineral acid => Reduced sulfate accumulation in the pool water
- Little or no manual addition of sodium bicarbonate required to maintain total alkalinity

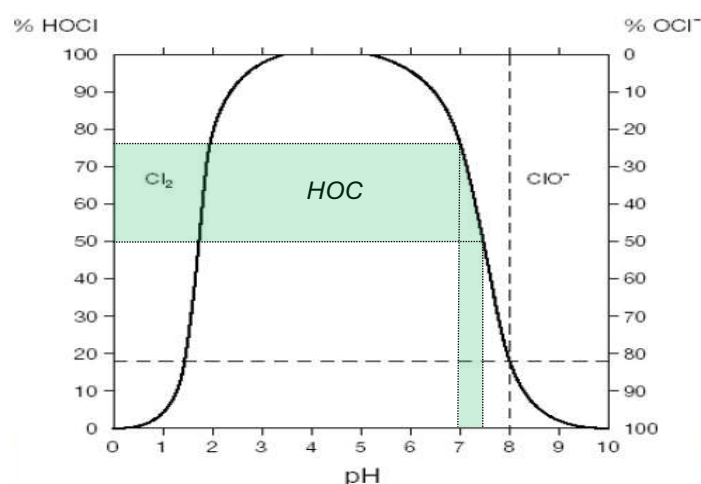
5. Disinfection, Effectiveness, and the Influence of pH

Disinfection is the central element of hygienic safety. In chlorine-based systems, not all forms of free chlorine are equally effective. The decisive factor is the proportion of active, unbound hypochlorous acid (HOCl). The pH value directly influences disinfection effectiveness because, as pH increases, a larger proportion of the free chlorine shifts into the less effective hypochlorite ion form (OCl^-). In addition, cyanuric acid can bind part of the free chlorine and thereby reduce the effective disinfection performance.

Free chlorine (chlorine measured by the DPD1 method) consists of the actively effective hypochlorous acid (HOCl), also referred to as active chlorine, the significantly less effective hypochlorite ion (OCl^-), and chlorine that is bound to cyanuric acid (chlorinated cyanurates), which is not considered actively effective.

$$\text{Free Chlorine (DPD1)} = \text{HOCl} + \text{OCl}^- + \text{Chlorinated Cyanurates}$$

The primary disinfecting species is the actively effective hypochlorous acid (HOCl). At excessively high pH values, the equilibrium shifts towards hypochlorite (OCl^-), and the oxidation-reduction potential (ORP/redox value) decreases despite an apparently sufficient free chlorine concentration.



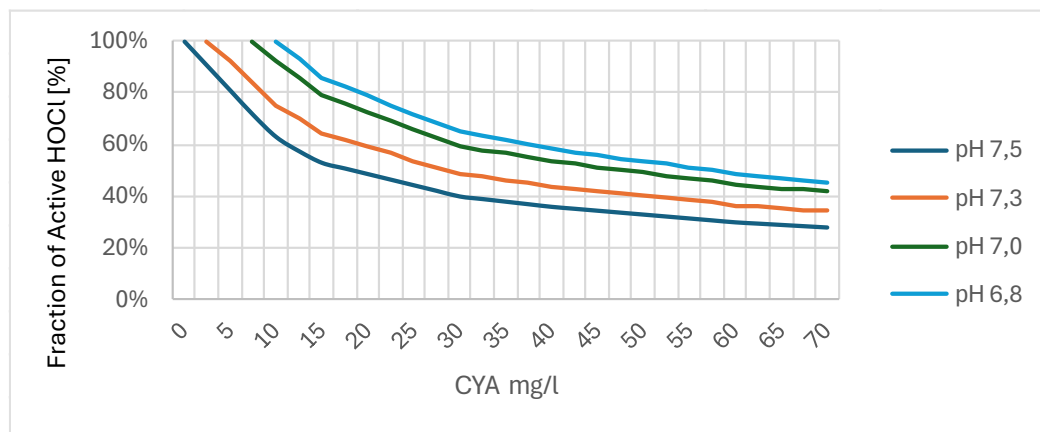
An elevated cyanuric acid concentration can also significantly reduce disinfection effectiveness and may lead to algae growth and inadequate disinfection despite apparently high free chlorine levels.

Historical studies demonstrate a clear relationship between redox potential and the inactivation of *E. coli* in chlorinated water [14]:

Redox potential	Disinfection time
450 – 500 mV	167 Min
500 – 550 mV	6 Min
550 – 600 mV	1,7 Min
600 – 650 mV	0,5 Min
> 700 mV	few seconds
Time required to inactivate 99.9% of <i>E. coli</i> depending on redox potential in chlorinated water (pH 7)	

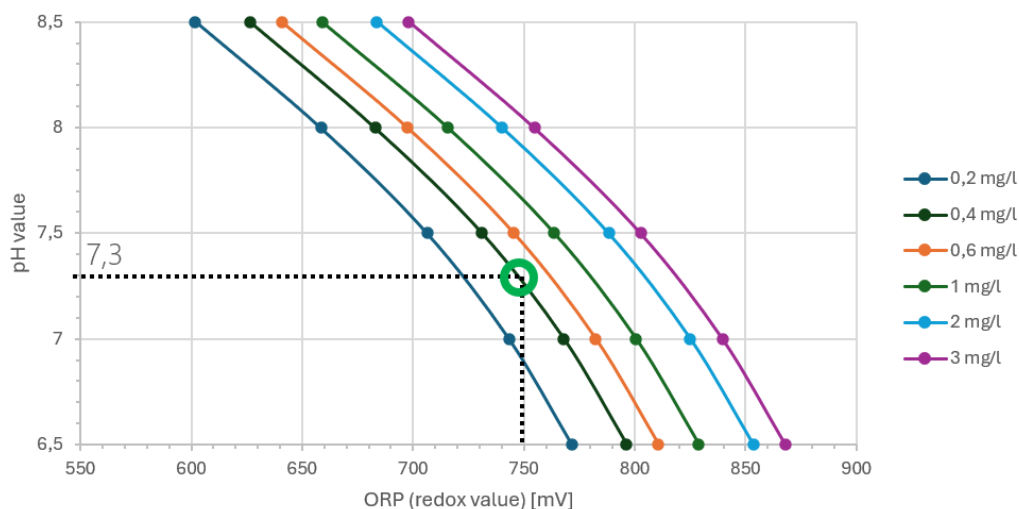
Note: The values refer to the experimental conditions described in the underlying study and should not be interpreted as universally applicable disinfection times for arbitrary swimming pools or water compositions.

The following provides an indicative guide to the actual effectiveness of chlorine as a function of cyanuric acid concentration at different pH values:



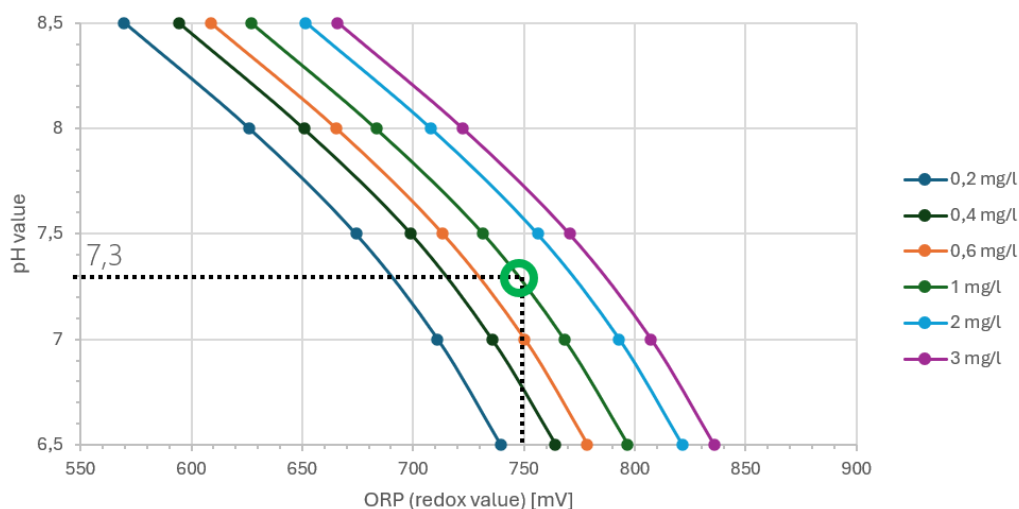
This relationship can also be illustrated by the following diagram, which presents a simplified model for visualizing the correlation (Note: actual ORP and chlorine values may vary depending on the water composition):

Redox vs. free chlorine for different pH values (T=28°C, CYA=0 mg/l)



No CYA $\Rightarrow$ 2/3 of the free chlorine (DPD1: 0.4 mg/L) is actively effective $\triangleq$ 0.25 mg/L HOCl (unbound)

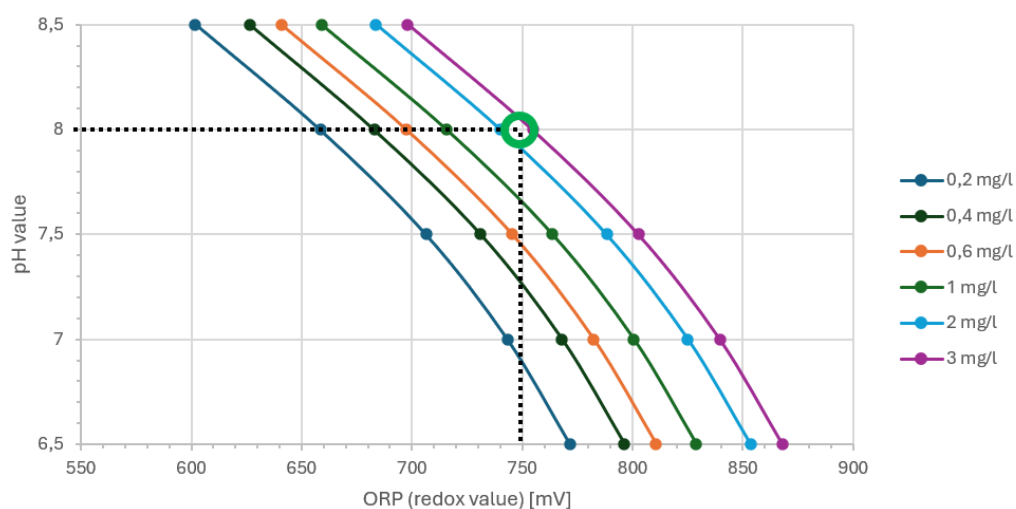
Redox vs. free chlorine for different pH values (T=28°C, **CYA=35 mg/l**)



35 mg/l CYA ⇒ doubles the required free chlorine concentration (DPD1: 0.4 → 1.0 mg/L)

Risk of overdosing if cyanuric acid is present in the water and is not taken into account during calibration!

Redox vs. free chlorine for different pH values (T=28°C, **CYA=0 mg/l**)



High pH Value (e.g. pH 8.0) ⇒ significantly increased required free chlorine concentration (DPD1: 0.4 → 2.0 mg/L)

Risk of overdosing if the pH sensor is malfunctioning, drifting, or has been incorrectly calibrated!

For the operator, this means that disinfection performance should not be assessed solely on the basis of a single parameter. Instead, the relationship between free chlorine, pH value, cyanuric acid concentration, and redox behaviour must be taken into account. Under unfavourable conditions, an apparently adequate chlorine concentration may be significantly less effective than expected. Stable water treatment therefore also requires these influencing factors to be checked regularly and adjusted when necessary.

6. Corrosion of Stainless Steel – Causes and Prevention

The stainless steel used in swimming pools is typically an austenitic stainless steel (e.g. AISI 316L / EN 1.4404), which exhibits high corrosion resistance under suitable operating conditions. The key requirements include:

- Use of clean fill water with the lowest possible chloride concentration.
- Correctly adjusted water parameters, particularly:
 - Chloride concentration
 - Total Alkalinity (TA) / acid-neutralizing capacity
 - pH value
 - Free chlorine concentration
- Avoidance of excessive water temperatures (maximum 32°C for short periods).
- Proper dosing and adequate distribution of pool treatment chemicals.
- Use clean, low-metal fill water (do not fill the pool via fire hydrants, as iron, manganese, copper, and rust particles may be introduced into the system, increasing the risk of corrosion).
- Avoidance of direct contact with concentrated chemicals.
- Regular filtration with sufficient circulation rates to prevent stagnation and dead zones.
- Regular inspection and cleaning of stainless-steel surfaces to remove deposits and surface contamination.
- Use of a metal ion Sequestrant Agent.
- Avoid contamination of stainless-steel surfaces (e.g. by tile cleaners, mortar or cement residues, or iron particles originating from tools, grinding, or cutting operations).
- During the installation of stainless-steel components, only suitable tools specifically intended for use with stainless steel should be used. Contact with unsuitable tools or tools and auxiliary equipment previously used for working on unalloyed or low-alloy steels should be avoided, as this can transfer foreign iron particles onto the stainless-steel surface, potentially causing localized corrosion at the affected areas.

Corrosion phenomena are typically promoted by the interaction of several factors. Elevated chloride concentrations, unfavourable hydraulic conditions, deposits on stainless-steel surfaces, and elevated temperatures are considered particularly critical.

Previous contact with highly acidic cleaning agents or concentrated chlorine-based water treatment products may also locally damage the protective passive layer of the stainless steel.

The actual corrosion process often develops gradually and may only become visible weeks later through the appearance of rust or other signs of corrosion.

Note on the Use of Metal-Ion Sequestering Agents

Metal-ion sequestering agents may affect the measurement and control of pool water depending on their chemical composition, dosage and the specific water conditions. This applies in particular to redox measurements and the amperometric measurement of free chlorine. The extent of the effect may vary depending on the water composition and the product used and, under unfavourable conditions, may also result in impairment or persistent fouling of the electrode surface.

When treating pool water with metal-ion sequestering agents, it is therefore recommended to deactivate the automatic measuring and control system for the first 24 hours and interrupt the flow through the measuring cell. After this contact period, the system should be put back into operation and the behaviour of the measurement values should be carefully monitored over the following days.

In particular, the redox and free-chlorine measurements may differ from the values recorded prior to treatment. Where necessary, the measuring cell and/or electrodes should be inspected, cleaned or recalibrated, and the control parameters adjusted accordingly.

Chloride Input

With the exception of pools operated with saltwater electrolysis systems, chlorides are introduced into swimming pool water primarily through the use and subsequent conversion of chlorine-based disinfectants. In the case of liquid chlorine, the chloride load is further increased by the manufacturing-related sodium chloride content, which typically ranges from 10 to 12.5 wt.% in commercially available 12.5% sodium hypochlorite solutions. Under normal pool operating conditions, chloride is removed almost exclusively through dilution by partial water replacement.

Note: Hydrochloric acid-based pH reducers would further increase the chloride concentration. In practice, however, sulfuric acid-based pH reducers are predominantly used and do not contribute additional chlorides.

Example for a 30 m³ Pool:

- One 25 kg container of liquid chlorine (12% available chlorine)
→ increases the chloride concentration by up to **130 mg/L**
- The available-chlorine-equivalent of 4.5 kg calcium hypochlorite (68–70%), or equivalent to 15 organic chlorine tablets of 250 g each (~90 wt% trichloroisocyanuric acid)
→ increases the chloride concentration by up to **70 mg/L**
- One 20 kg container of liquid pH reducer (14.9% sulfuric acid)
or the equivalent amount of 7.5 kg pH-minus granules (Sodium Bisulfate)
→ reduces alkalinity by up to approximately **100 mg/L as CaCO₃**

If these chemicals are used over extended periods without sufficient water replacement, water parameters may gradually shift into a range that is unfavourable for stainless steel.

Annual Pool Refill Operation

For pools that are completely refilled annually, no additional large-scale partial water replacement is generally required when using liquid chlorine dosing, provided that the consumption of chlorine containers (25 kg, ~12% available chlorine) **does not exceed one container per 10 m³ of pool volume per season and the chloride concentration of the fill water remains below 100 mg/L**. In this case, the small water replacements resulting from regular filter backwashing are considered sufficient.

***Note:** For this reason, care should be taken to use the freshest possible chlorine containers, as available chlorine content decreases with age and improper storage conditions. Consequently, larger product quantities may be required to achieve the same disinfection performance.*

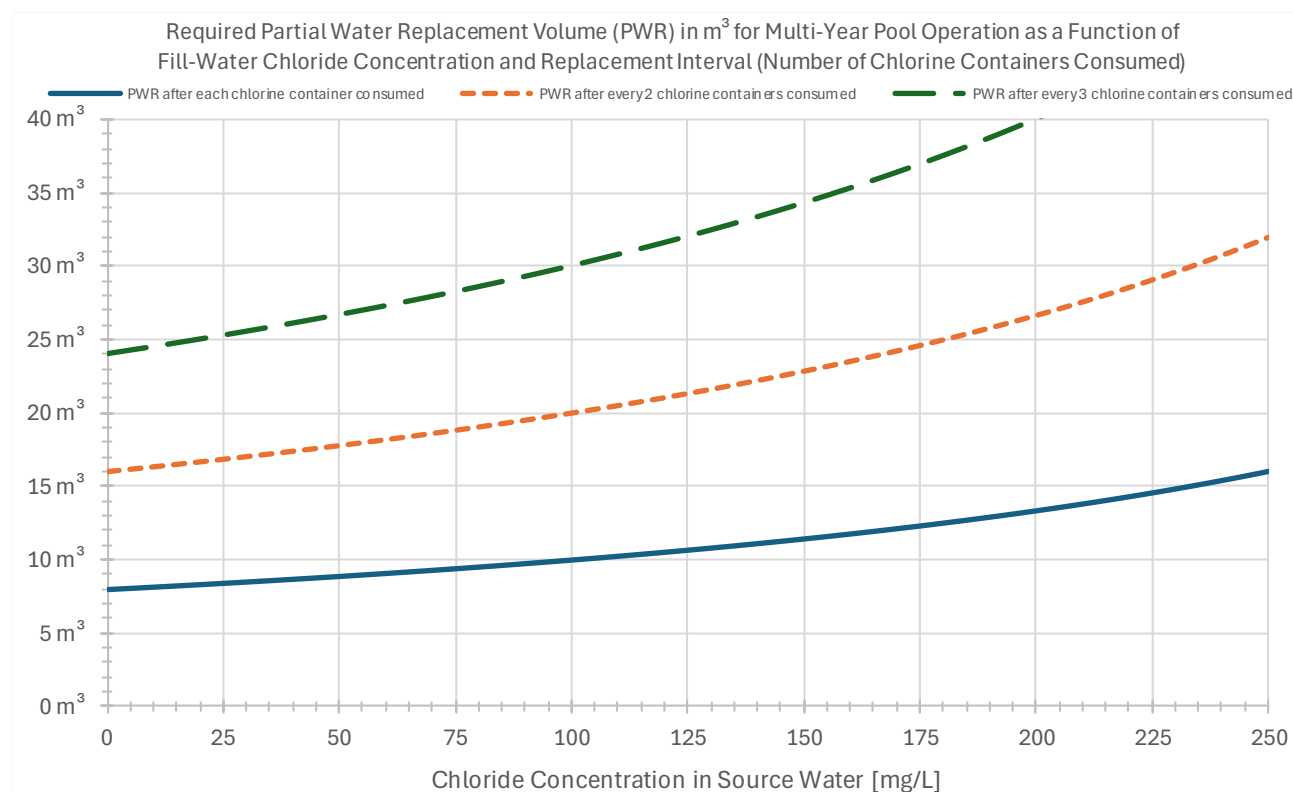
Multi-Year Pool Operation with Continuous Partial Water Replacement

In pools operated over multiple years without complete refilling, regular larger-volume partial water replacement is required to maintain chloride concentrations within a range favourable for stainless steel. The required replacement volume is primarily determined by the chloride concentration of the fill water, whereas the optimal replacement interval depends mainly on chlorine consumption.

For long-term pool operation, the required partial water replacement (PWR) can be calculated using the following equation as a function of the fill-water chloride concentration and the selected replacement interval. In this simplified model, the calculation ensures that the chloride concentration does not exceed, e.g. 500 mg/L. The corresponding relationship is illustrated in the diagram below.

$$PWR [m^3] = \frac{N_{\text{container}} \cdot m_{\text{Cl}^-}}{500 - Cl_{\text{fill}}}$$

$N_{\text{container}}$ = Number of 25 kg sodium hypochlorite containers consumed
 m_{Cl^-} = 4000 g of chloride generated per 25 kg sodium hypochlorite container
 Cl_{fill} = Chloride concentration of the fill water [mg/L]



Note: The change intervals are specified as the number of chlorine containers consumed between two partial water changes

The higher the chloride concentration of the fill water and the less frequently partial water replacement is performed, the greater the volume of water that must be replaced.

Recommended rapid method for determining the chloride concentration: chloride test strips

Importance of Alkalinity

In addition to chloride concentration, alkalinity (TA or acid-neutralizing capacity) plays a key role in achieving stable and low-corrosion operation. Continuous dosing of sulfuric acid for pH control gradually reduces alkalinity. If alkalinity falls too low, large pH fluctuations become more likely, making corrosive operating conditions easier to develop.

When alkalinity drops below approximately 60 mg/L as CaCO_3 , sodium bicarbonate (according to EN 15075) should therefore be dosed regularly.

As a rule of thumb, **~5 kg of sodium bicarbonate** according to EN 15075 should be added **for every container of pH-minus** product consumed (20 kg, 14.9% sulfuric acid).

The addition should be distributed over the consumption period in several smaller weekly doses.

Influence of Iron and Metal Deposits

Elevated iron concentrations in the fill water can promote the formation of iron oxide deposits on stainless-steel surfaces. Particularly in hydraulically poorly flushed areas, such deposits can create localized differential aeration cells (oxygen concentration cells). The restricted oxygen supply impairs repassivation of the stainless-steel surface and locally reduces the stability of the passive layer. Once the passive layer begins to break down locally, metal ions are released from the stainless steel. Hydrolysis of these ions immediately adjacent to the metal surface results in localized acidification. If alkalinity is too low, this local acidification cannot be adequately buffered, leading to destabilization of the passive layer and increasing the risk of corrosion phenomena such as:

- Under-deposit corrosion
- Crevice corrosion
- Pitting corrosion

Elevated chloride concentrations, higher temperatures, and high oxidation-reduction potentials further intensify these effects. For this reason, the cleanest possible fill water with low iron content should be used. Filling the pool via fire hydrants should be avoided whenever possible, as depending on the condition and design of the water supply system, iron, manganese, copper, or rust particles may be introduced into the water.

Where fill water contains elevated concentrations of iron or other metals, suitable pre-treatment (e.g. iron filtration) is recommended. In addition, an appropriate metal ion Sequestrant Agent should be dosed regularly in accordance with the operating instructions. Sequestrants reduce the precipitation and deposition of metal compounds and should be used not only during commissioning but continuously throughout operation.

Handling of Chemicals

The protective passive layer of stainless steel can be damaged by direct contact with concentrated chemicals. Particularly critical are:

- Hydrochloric acid-based pool cleaners
- Concentrated sodium hypochlorite solutions
- Localized high concentrations of calcium hypochlorite

Such products must never come into direct contact with stainless-steel surfaces. Likewise, liquid chlorine and other treatment chemicals should not be introduced into the pool in the immediate vicinity of stainless-steel fittings or hydraulically stagnant areas. Adequate dilution and rapid distribution throughout the pool water must always be ensured.

Cleaning and Maintenance of Stainless-Steel Surfaces

Deposits, surface rust contamination, and other surface films should be removed regularly in order to preserve the natural passive layer of stainless steel. Suitable products for cleaning, restoring, and passivating stainless-steel surfaces in an emptied pool should be obtained from a specialist pool supplier.

Example: citrate-based stainless steel cleaner for rust removal and passivation

The earlier corrosion initiation sites are removed, the greater the likelihood of complete surface restoration.

Design of Stainless Steel Components and Fittings

In addition to material selection and water quality, the design and construction of a stainless steel component also have a significant influence on its long-term durability.

Crevices and poorly accessible gaps should generally be avoided. This applies in particular to overlapping clamped and push-fit connections, as well as other design-related crevices in which water, chlorides and deposits can accumulate [12]. Where crevices are unavoidable for design reasons, they should be made as wide as possible [13].

For components installed in swimming pools, the aim should therefore be to use a design that is as simple, crevice-free and easy to clean as possible. Unnecessary numbers of bolted, clamped, push-fit, welded or other connection points should be avoided.

The following design principle therefore applies to stainless steel components installed in swimming pools: The simpler, smoother, more crevice-free and more accessible a component is designed, the fewer potential corrosion sites it will have, and the easier these sites can be inspected and cleaned.

This can also be illustrated using a simplified probability calculation. Assuming that each of (n) independent detail or connection points has an individual probability (p) of developing a corrosion phenomenon within a given period under unfavourable operating conditions or conditions in which the water parameters deviate from the recommended values, the probability that at least one of these points will be affected is:

$$P_{ges} = 1 - (1 - p)^n$$

With 100 connection points, an individual probability of just 0.1% already results in $P_{ges} = \sim 10\%$.

Note: This calculation is intended solely as a mathematical, hypothetical example. It cannot be used to derive a generally applicable probability of corrosion for a specific stainless steel connection or a particular component.

Conclusion

The long-term corrosion resistance of stainless steel in swimming pools can be supported by maintaining the recommended water parameters, performing regular partial water replacement, ensuring adequate alkalinity, providing favourable hydraulic conditions, using sequestrants, and following proper cleaning and maintenance procedures.

7. Care, Maintenance and Operational Awareness

Reliable pool operation requires more than simply adding chemicals. It primarily demands discipline in maintenance and care. Measurement values should be checked for plausibility at least once per week. Total alkalinity should be monitored regularly, as should the functionality of sensors and measuring points. Filter backwashing, proper storage of liquid chlorine, and the timely replacement of aged sensors are just as important for careful operation as understanding the interactions between pH, temperature, cyanuric acid, and disinfection performance.

For measuring electrodes, the following points should be observed in addition to the manufacturer's instructions:

- Always store and transport electrodes in an upright position, in storage solution, and protected from frost.
- Electrodes age even when not in use.
- The ORP value is strongly influenced by pH and cyanuric acid.
- Cyanuric acid can impair certain membrane-covered free-chlorine sensors.
- Wear of a pH electrode results in a noticeable signal loss within a single season, leading to measurement drift

Note: *The raw signal loss is typically in the range of approximately 40 mV per season. Depending on the electrode slope, this corresponds to a pH drift of approximately 0.4 or more (depending on the actual electrode slope).*

Example: *If a pH sensor is freshly calibrated at the beginning of the season and is not recalibrated during the season, a systematic measurement error will occur. In practice, this means that at the end of the season the display may still indicate a pH value of 7.2, while the actual pH of the water is already around 6.8.*

- Measuring electrodes should ideally be replaced annually.
- Where possible, use systems with two-point calibration, as this allows the slope and thus the functionality of the measurement to be reliably assessed.

Chlorine Dosing Using Monitoring, Control and Dosing Systems (MCD Systems)

In private swimming pools, monitoring, control and dosing systems (MCD systems) are frequently used that regulate chlorine dosing based on the oxidation-reduction potential (ORP sensor). These systems are comparatively inexpensive and easy to operate. For the pool volumes typically found in private applications, usually up to about 50 m³, this principle often performs satisfactorily in practice because the inertia of the overall system remains manageable.

However, the ORP value does not directly measure the concentration of the disinfectant and should therefore not be equated with the actual free chlorine concentration. Rather, it provides an indication of the disinfecting effectiveness of the water. ORP is influenced by factors including water contamination, cyanuric acid concentration, temperature, pH, and electrode condition. For this reason, ORP is used in public swimming pools only as a supplementary hygiene indicator, while chlorine dosing is controlled by direct measurement of free chlorine.

In private applications, ORP-based control using high-quality ORP sensors has nevertheless proven effective, provided that sensor functionality is regularly checked, calibrated, and replaced when necessary (typically annually). These sensors generally offer adequate response times (the reading in a reference or calibration

solution should stabilize within 30 seconds), high measurement resolution, and low measurement variance. The same applies to pH electrodes, whose slope should exceed 55 mV/pH.

Amperometric chlorine sensors (“true free chlorine electrodes”) are also available on the market. In theory, these systems are more precise because they directly measure the concentration of free chlorine. However, this requires regular calibration, cleaning, and maintenance. Practical experience shows that, particularly in private pools, such sensors tend to suffer from oxidation and contamination after extended shutdown periods, reduced pump operation (ECO mode), or winter shutdowns. Without manual cleaning, significant measurement deviations can occur. Even frequently advertised self-cleaning measuring cells, in which small balls are intended to clean the sensor, often fail to provide sufficient cleaning under such conditions.

In addition, calibration of free-chlorine electrodes is often performed in practice as a single-point calibration only. This can easily create the impression that the chlorine value is being measured “exactly”. In reality, however, the sensitivity (electrode slope) may already be significantly reduced. In such cases, a seemingly constant chlorine value is displayed even though the actual chlorine concentration in the pool water may differ substantially. The result is increased measurement uncertainty and significantly reduced reliability of the measurement.

The use of free chlorine sensors and/or redox control in private pools requires consistent maintenance, as well as regular verification and plausibility checks of the measured values. Where redox control alone is used, operation is generally relatively straightforward for private pool owners under suitable operating conditions, provided that only inorganic chlorine is used and the introduction of cyanuric acid is avoided.

8. Algae Growth Despite Correct Water Parameters

Even when water parameters appear to be within the recommended range, algae problems can still occur. This is because the routine measurements typically performed during pool operation—particularly pH, free chlorine, cyanuric acid, and total alkalinity—do not capture all factors that may influence algae growth. In particular, phosphates, hydraulic deficiencies, and biofilms often remain undetected.

Algae spores are continuously introduced into pool water through the air, bathers, and other environmental sources. Whether these spores develop into visible algae growth depends on the interaction of numerous biological, chemical, and hydraulic factors. The most important of these are explained below.

Free Chlorine

Chlorine acts as a disinfectant, oxidizing agent, and algistat. Short-term reductions below the recommended free chlorine concentration do not necessarily result in algae growth, particularly where good pool hydraulics and a low organic load are maintained. However, persistently low chlorine levels significantly increase the risk of algae development. More resistant species, such as mustard algae or so-called black algae, are considerably more difficult to remove than common green algae.

To prevent algae growth, a stable residual disinfectant level should be maintained. Where necessary, regular shock chlorination is recommended, preferably using inorganic chlorine (e.g. calcium hypochlorite).

pH

The effectiveness of chlorine depends strongly on pH. As the pH value increases, the proportion of highly effective hypochlorous acid decreases. For private swimming pools, a pH value between 7.0 and 7.4 is therefore generally recommended.

Note: Since the pH value continuously increases due to CO₂ outgassing, automatic pH control is particularly recommended for heated swimming pools. Adequate total alkalinity (TA) should be maintained to ensure stable pH control.

Caution: Manual pH measurements using Phenol Red tablets may produce unreliable results when total alkalinity is very low.

Cyanuric Acid (Chlorine Stabilizer)

Cyanuric acid is introduced into the water primarily through stabilized chlorine products such as conventional chlorine tablets and chlorine granules. These products have the advantage that, unlike inorganic chlorine, they have only a minor effect on the pool water pH, while the contained cyanuric acid protects chlorine from rapid degradation by UV radiation. However, as the cyanuric acid concentration increases, the proportion of active hypochlorous acid (HOCl) decreases, thereby reducing both disinfection efficiency and algae control.

Example: A shock treatment with stabilized chlorine can increase the cyanuric acid concentration by up to 10 mg/L. A single long-lasting chlorine tablet typically increases the cyanuric acid concentration in a 30 m³ pool by approximately 4–5 mg/L.

At cyanuric acid concentrations of approximately 50 mg/L or higher, the effectiveness of disinfection and algae control is reduced to less than one-third of its original level. Therefore, the cyanuric acid concentration should be monitored regularly and maintained below 50 mg/L.

At a cyanuric acid concentration of only 20 mg/L, more than 4 mg/L free chlorine (DPD1) is required to achieve the same effectiveness as 0.5 mg/L free chlorine in the absence of cyanuric acid [10,11].

Although lower chlorine concentrations are often sufficient for hygienic disinfection, higher levels may be required for reliable algae prevention. At a cyanuric acid concentration of approximately 25 mg/L, at least 2 mg/L free chlorine (DPD1) is generally recommended in practice for reliable algae prevention. For an additional safety margin, a target range of 3–4 mg/L free chlorine (DPD1) has proven effective.

Water Temperature

As water temperature increases, both chlorine demand and the growth rate of microorganisms and algae increase. Warm, nutrient-rich, and poorly mixed areas of the pool are particularly susceptible to algae growth. Swimming pools operated at temperatures above 28 °C therefore require more intensive water treatment and more frequent monitoring of water parameters.

Nutrient Input (Phosphate and Nitrate)

Phosphate and nitrate are among the most important nutrients for algae growth. While nitrate generally plays only a minor role in private swimming pools, phosphate is often the limiting nutrient. **Reducing the phosphate concentration can therefore significantly restrict algae growth.** Phosphate and nitrate enter swimming pools through various pathways, including bathers, environmental contamination, and the fill water.

As phosphate concentrations increase, the risk of algae growth also increases. In practice, algae problems are observed more frequently when phosphate concentrations exceed approximately 1 mg/L, particularly if other unfavorable conditions are also present. At the same time, elevated phosphate concentrations frequently increase chlorine demand and, consequently, chlorine consumption. Targeted phosphate removal can therefore significantly reduce both maintenance requirements and chlorine consumption. To reduce elevated phosphate concentrations, appropriate phosphate-removing agents may be used. The dosage and application method should be determined in accordance with the manufacturer's instructions and the specific water characteristics.

Chlorine kills algae but does not remove nutrients from the water. Consequently, elevated phosphate concentrations remain even after shock chlorination and may promote renewed algae growth.

Note: Some drinking water suppliers intentionally add orthophosphate to the drinking water distribution system as a corrosion inhibitor. As a result, fill water may already contain elevated phosphate concentrations.

If elevated phosphate concentrations are detected in the fill water, the use of a suitable phosphate filter in the fill-water supply line is recommended.

Pool Hydraulics and Water Circulation

Poorly circulated areas and hydraulic dead zones promote the accumulation of deposits, biofilms, and algae. While reducing pump flow rates may improve filtration efficiency by lowering filter velocities, it can also impair water circulation within the pool and reduce the effectiveness of disinfection in poorly circulated areas. Particularly when using variable-speed pumps, attention should therefore be paid not only to achieving an optimum filtration velocity but also to ensuring adequate circulation throughout the entire pool. The objective of good pool hydraulics is to ensure that all areas of the pool are continuously and as uniformly as possible supplied with adequately disinfected water.

Biofilms form preferentially inside pipework, hydraulic dead zones, skimmers, automatic cover recesses, and other poorly circulated areas. They provide microorganisms with effective protection against chlorine disinfection and may serve as a source of recurring algae outbreaks. Well-designed pool hydraulics, regular mechanical cleaning, and occasional shock chlorination all contribute significantly to preventing biofilm formation and reducing existing biofilms.

Condition of the Filtration System

Dirty or undersized filtration systems, as well as unsuitable filter media, reduce water quality and impair the removal of suspended solids, microorganisms, and algae spores. As a result, chlorine demand and, consequently, chlorine consumption increase. Regular backwashing, adequate filtration times, appropriate

filtration velocities, and clean filter media are essential prerequisites for maintaining an algae-free swimming pool.

Cleaning and the Use of Algaecides

Regular brushing of pool walls and floors removes deposits and biofilms, making it more difficult for algae to become established. Algaecides can provide additional inhibition of algae growth. However, they can never replace adequate disinfection or effective water treatment. Copper-based algaecides should be avoided whenever possible, as they may cause staining and deposits on pool surfaces, particularly under unsuitable water chemistry conditions.

Conclusion

In most cases, algae growth cannot be attributed to a single cause but rather to the interaction of several unfavorable factors. Effective long-term algae prevention therefore requires an integrated approach comprising adequate disinfection, stable pH control, low cyanuric acid and phosphate concentrations, good pool hydraulics, efficient filtration, and regular cleaning. When these factors are consistently maintained, algae growth can generally be prevented reliably without the routine use of algaecides.

9. Deposits

Particularly at elevated water temperatures and in cases of irregular or insufficient partial water replacement, the water may become increasingly concentrated with dissolved salts and substances such as phosphates, sulfates, or silicates. In combination with calcium or magnesium, and especially in the presence of temporary pH fluctuations, these substances can form deposits that visually resemble limescale but cannot be removed, or can only be removed to a limited extent, using acidic cleaners.

Such deposits tend to progress more rapidly when the affected surfaces have already become dulled or matt.

10. Best Practices

- **Verify the plausibility of control-system measurements at least once per week**
- Store liquid chlorine properly and use it within the recommended storage period
 - Ensure that fresh chlorine products are used, as chlorine degrades rapidly (~1 g/L per day).
Note: During the storage of available chlorine products (e.g. in containers), chlorate may form under unfavourable conditions.
Example: 3 months of storage under unfavourable conditions (25°C):
 ⇒ Reduction of available chlorine content (≈ 50%)
 ⇒ Increased chemical consumption (≈ factor 2x)
 Monitor the chloride concentration in the pool resulting from chemical additions.
 The addition of 25 kg of fresh sodium hypochlorite (12% available chlorine) to a 30 m³ pool can increase the chloride concentration by up to 130 mg/L.
 The addition of the available-chlorine-equivalent amount of 4.5 kg calcium hypochlorite (68–70%) or 15 organic chlorine tablets of 250 g each (~90 wt.% trichloroisocyanuric acid) to a 30 m³ pool can increase the chloride concentration by up to 70 mg/L over the long term.
- Check the TA value at least once per month
 - When using sulfuric acid for pH control, compensate as required with sodium bicarbonate:
 The addition of 20 kg of liquid pH reducer (14.9% sulfuric acid)
 or the equivalent amount of 7.5 kg pH-minus granules (sodium bisulfate) to a 30 m³ pool
 - **reduces the carbonate alkalinity** by ~100 mg/L as CaCO₃ (± 5.7 °dKH)
 - **increases the sulfate concentration** by ~100 mg/L.
 - When pH is controlled using CO₂ and chlorination is performed with sodium hypochlorite:
 A 25 kg container of sodium hypochlorite (12–13% available chlorine) can increase the carbonate alkalinity of a 30 m³ pool by up to approximately 50 mg/L as CaCO₃. This corresponds approximately to the alkalinity increase achieved by adding 3.4 kg of sodium bicarbonate (NaHCO₃).
 - Regular small increases in buffering capacity are preferable to a single large adjustment
- Backwash intervals should be determined according to the filter type, filter loading, pressure loss, and the manufacturer's recommendations (ensures also regular partial water replacement).
Attention: Insufficient filter cleaning can lead to the following problems
 - ⇒ Increased filter pressure
 - ⇒ Insufficient flow across measuring sensors
 - ⇒ Reduced self-cleaning effect of electrodes
 - ⇒ Increased tendency towards oxidation and deposit formation on electrodes
 - ⇒ Increased measurement deviation
 - ⇒ Overdosing

- For variable-speed pumps, ensure sufficient daily water turnover and adequate circulation throughout the pool (improves filtration efficiency)
Attention: *Insufficient circulation performance (excessive ECO mode operation or insufficient filtration time) can lead to:*
 - ⇒ Hydraulic dead zones (locally insufficient disinfection)
 - ⇒ Increased risk of biofilm formation and algae growth
- Replace measuring sensors annually and calibrate them regularly.
- Consider the influence of cyanuric acid (CYA) and pH on chlorine effectiveness.
Note: *Although CYA reduces UV-related chlorine degradation, it also reduces the proportion of effective chlorine. For example:*
 - At 0 mg/L CYA: ~35% active chlorine loss within 1 hour ☹
 - At 20 mg/L CYA: ~5% active chlorine loss within 1 hour ☺, but:
 - ⇒ Reduces the proportion of effective chlorine from 100% to ~60% ☹
 - ⇒ Dampens ORP measurement response ☹
 - ⇒ Requires double the chlorine concentration ☹
 - ⇒ Leads to chlorine overdosing at very high CYA concentrations ☹
 - ⇒ high process instability with true free-chlorine sensors
 (CYA measurement cannot be automated) ☹
- Monitor the CYA concentration in the pool in case organic chlorine is used
 - Organic (stabilized) chlorine generally has little or no effect on pH. The drawback is the introduction of cyanuric acid (CYA): In a 30 m³ pool, organic chlorine can increase the cyanuric acid concentration (CYA) as follows:
 - Slow-dissolving tablet (250 g with ~90wt% trichloroisocyanuric acid) → **+4,3 mg/L**
 - Shock chlorination as recommended by the manufacturer with fast-dissolving chlorine:
 - 600 g tablet or granules (~55wt% trichloroisocyanuric acid) → **+6 mg/L**
 - 600 g tablet or granules (~55-60wt% dichloroisocyanuric acid) → **+10 mg/L**

=> Shock chlorination should preferably be carried out using inorganic chlorine, particularly when the cyanuric acid concentration is already elevated!
- **Do not mix inorganic and organic chlorine products:**
 Mixing incompatible chlorine products can result in violent chemical reactions, fires, or explosive reactions.

11. Concluding Remarks

The quality of a GRP pool does not depend solely on the quality of its material and surface finish, but to a large extent on water chemistry and operational management. Many visible phenomena occurring on the pool shell should not be regarded exclusively as material defects, but rather as the result of an interaction between chemical exposure, operating conditions, and operator behaviour.

This chapter is therefore intended to serve as a guide for interpretation and assessment. It explains the underlying chemical principles while also demonstrating why careful maintenance and operational awareness are essential for preserving the functionality, appearance, and service life of a GRP pool over the long term.

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